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THE HISTORY OF THE CITY OF BOSTON

BY
JOHN H. COLEMAN

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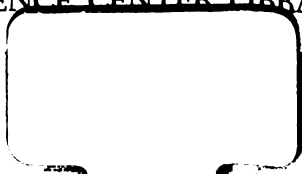
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AIR AND WATER

BY

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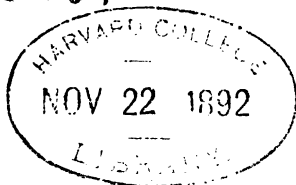
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PREFACE.

IN this little book I have attempted to bring before my readers the wonderful changes and actions which are going on around them in our atmosphere, and the even more marvellous work which water is performing in nature.

A knowledge of the relations which exist between our health and the air we live in, and of the effects which water and its various impurities have upon our system, is so important, and has so wide a bearing upon the comfort and well-being of the human race, that this knowledge should form an important factor in our National Education.

Unfortunately it is only of late years that the true importance of natural science has been recognized, and it is often found that amongst the well-educated classes but little is known of the subject, whilst in an ordinary commercial education the time devoted to science is small indeed.

I have endeavoured here to tell the story of Air and Water in the simplest possible language, and by divesting my subject as far as possible of scientific technicalities, to make clear to non-scientific readers the wonderful beauty of those great natural processes upon which our healthy life depends, and I hope by so doing to create in them an interest for the subject which shall lead to scientific study for its own sake.

I am indebted to Messrs. Whittingham and Co. for the use of some of the illustrations from my book on *Service Chemistry*, to which I must refer my readers for a more extended discussion of the laws underlying this most beautiful of the sciences.

V. B. L.

Greenwich, 1892.

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AIR AND WATER.

CHAPTER I.

THE HISTORY OF THE ATMOSPHERE.

SOME thousands of years before the Christian era formed the great time-mark of history, the Hindu philosophers recognized around them a gaseous something, which they gradually came to look upon as the chief of the small band of the then so-called elements, air, earth, fire and water—imagining that from air the other three could be formed, whilst of all four the world itself was built up.

The fact that air in motion exerted considerable power upon exposed surfaces, and that its force could be utilized, as is the case with a windmill or the sail of a ship, gave rise even before the time of Aristotle to the idea that air probably had weight, and 350 years B.C. that great philosopher tried to demonstrate the fact by weighing an empty bladder and then inflating it with air, an experiment which gave a slight increase of weight. The reason of this increase, however, was pointed out by Simplicius at the time to be that moist air from the lungs had been employed, and that when the experiment was repeated with perfectly dry air, no increase in weight could be detected.

The reason of the weight of the air not being found by this method is evident, when you consider that the empty bladder displaces practically no air, but when inflated, displaces as much as it contains, and inasmuch as the weight of any substance in air is its weight less the weight of air displaced, the bladder must weigh the same either empty or full.

For more than sixteen centuries after Aristotle's time no important advance was made in the ideas existing with regard to the atmosphere—when at rest it was forgotten, when in motion it was considered a spirit; but with the rise of Galileo in the last years of the sixteenth century air began to have a history, as it was now that for the first time it was recognized that air was a ponderable substance; and it was Galileo who showed that if a strong copper globe is weighed when full of air at ordinary pressure, compressing more air into it increases its weight.

This fact may be more easily demonstrated by taking a strong glass globe fitted with a stop-cock, and exhausting it by means of an air pump. When exhausted, the globe is exactly counterpoised on a balance and the stop-cock opened, the air rushes in to fill the globe, and the increase in weight is at once made manifest by the descent of the beam.

By experiments such as this it is easy to show that the weight of any large volume of air is considerable, and exact determinations fix the weight, under normal atmospheric conditions, at 1 lb. per 13 cubic feet of air, or, expressed in more scientific language, 1 litre of pure air weighs 1.293 grams.

Towards the end of Galileo's career he made the acquaintance of a rising young philosopher named Torricelli, who

became his assistant ; and on the death of Galileo, in 1642, Torricelli continued several researches upon which his great master had been engaged, amongst them the explanation of the fact that it is impossible to suck water up by means of a pump to a greater height than about thirty-three feet.

In an ordinary pump the down-stroke of the handle lifts a piston which slides air-tight in the barrel of the pump, and so creates a partial vacuum, into which the water rises to take the place of the air ; and on now raising the handle, the piston descends, and the water being prevented from falling again in the pipe by means of a valve at the bottom of the barrel, passes through a valve in the descending piston, and with the next stroke is carried up to the spout of the pump, from which it escapes.

The fact that water was sucked up by the partial vacuum in the barrel of a pump had been known to Aristotle and the philosophers of his day ; but they explained it by saying that "nature abhorred a vacuum," a reason which, being endowed with a fine sonorous ring, perfectly well served the purposes of Natural Philosophy for nearly two thousand years, and no limit to it was found until Galileo observed that water could only be raised to a limited height by such means. In working at this subject Torricelli first determined the height to which water could be raised by means of a perfect vacuum in a tube ; and he found that with the best vacuum obtainable, the level of the water in his tube was from thirty-two to thirty-three feet higher than the surface of the water in which the tube stood ; and the constant recurrence of this height of column, suggested to him that there must be some force in nature of which the weight of a column of water of this height must be a measure ; and he reasoned that if this be so, if he used a liquid heavier than

water, then this force, whatever it might be, ought not to support so great a column.

After experimenting with several liquids, he finally decided upon using the liquid metal mercury, and taking a tube three feet long, he sealed it up at one end and filled it with the quicksilver, taking precautions to remove all bubbles of air, and then inverted the tube in a vessel of the same liquid. On removing his finger from the end of the tube under mercury, the column in the tube fell a few inches, and after oscillating up and down for a few seconds, came to rest, leaving above its surface the most perfect known vacuum, which is still called after its discoverer, "the Torricellian vacuum."

On measuring the height of the column of mercury so supported, he found it was thirty inches, and on determining the relative weights of mercury and water, he found that the former was 13.6 times as heavy as the latter. Now as 34 feet is 13.6 times greater than 30 inches, it is evident that the weight of the column of water and of mercury was the same; and this confirmed the truth of Torricelli's assumption.

The next point he set himself to clear up was the nature of the force which suspended these columns of liquid so far above the surface of the mass; and remembering Galileo's demonstration of the weight of air, he concluded that it must be the weight of the atmosphere pressing on the exposed surface of the liquid which drove it up in the vacuous tube until the weight of liquid and weight of air balanced each other.

The early death of Torricelli in 1647 prevented his seeing this theory adopted; indeed, it was only fully proved to be correct a year after his death, when Blaise Pascal succeeded

in clearly demonstrating its truth. He argued that if Torricelli had given the true explanation, and it was the weight of the atmosphere which supported the column of mercury, then if the apparatus could be taken to a great altitude, there being less weight of atmosphere above the particular spot, the column of mercury would not be supported at so great a height.

In order to carry out this experiment, Pascal invoked the aid of his friend Perier, who filled two similar tubes with mercury; and having noticed that the level of the mercury in each stood at the same height when they were inverted in bowls of the same substance, left one at the foot of a mountain, whilst he carried the other to the top. This experiment was made in Auvergne; and the mountain was the Puy de Dôme, during the ascent of which Perier found that the column of mercury gradually fell lower and lower, until on reaching the summit it was three inches lower than at the foot; whilst on descending the mountain the level of the mercury again rose, until, on reaching the level ground once more, it was found to have assumed the same level as in the standard tube which had been left behind.

This clearly proved that it was the weight of the atmosphere which supported the column of mercury, a fact which may also be proved by putting a tube filled with mercury and inverted in a vessel of mercury under the receiver of an air pump; on exhausting, the column gradually falls until, when a vacuum is obtained, the mercury stands at the same level inside and outside the tube.

Torricelli's tube is indeed an exact measure of the weight of the atmosphere, telling us not only that air has weight, but exactly how much the column of air above us weighs; and in after years this form of apparatus was called by Boyle

the "barometer," and we more often look upon it as a weather indicator than as a means of ascertaining the weight of the air.

In point of fact, the barometer tells us nothing about the weather, it merely indicates the weight of the column of air which extends away above us to the confines of the atmosphere, and it only rises or falls as the weight increases or diminishes. Change in weather, however, generally coincides with change in the pressure, so that although not necessarily connected, the one is generally taken as an indication of the other.

It is at first sight not always easy to realize that in Torricelli's tube it is the pressure of the atmosphere on the exposed surface of mercury which supports the thirty-inch column in the tube with a vacuum above it. This fact, however, becomes perfectly evident if the tube, instead of being straight and then inverted in a vessel of mercury, is made rather longer, and the open end is bent upwards; if such a tube be now filled with mercury and then exposed to atmospheric pressure, the mercury will stand at such a level in the closed limb of the tube that its surface is thirty inches above the surface of the mercury in the open limb, and as the only difference in conditions between the surface of the mercury in the open and closed limb, is that the atmosphere is pressing on one surface and not on the other, it is manifest that it is the atmospheric pressure which is doing this work.

Or if a large glass U tube be taken, each arm of which is thirty-three inches long, and open at each end, and if into this mercury be placed, the mercury will stand level in each arm of the tube (A, Fig. 1), but now if one end be closed and be then completely filled with mercury, on replacing the

tube in position, the mercury will only fall in the tube until the difference between the levels is thirty inches (B, Fig. 1), that is to say, the pressure of the atmosphere on the surface of the mercury in the open tube is able to balance a column of thirty inches of mercury in the closed arm of the tube with no air above it.

If the tube be made exactly one square inch in section, then the atmospheric pressure on the exposed square inch of mercury is able to support a column of mercury a square inch in section and thirty inches high, or thirty cubic inches. Now thirty cubic inches of mercury weigh 14.7 lbs., so that it may be said in round numbers, that the atmospheric pressure is 15 lbs. on the square inch, or nearly a ton (2,160 lbs.) on the square foot. A person of medium size will have a surface equal to about 16 square feet, and the pressure, therefore, which is supported by the body amounts to 35,560 lbs., or not far short of sixteen tons.

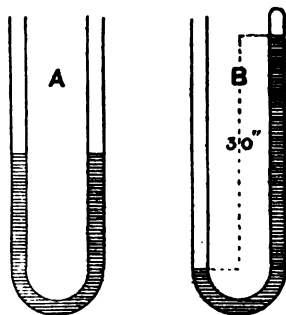


Fig. 1.

It seems at first sight impossible that the body could support this enormous weight, yet so wonderfully has nature arranged the balance that we are perfectly unaware of it, whilst the existence of it is necessary to keep our bodies in shape.

In our bodies the solid matter and skeleton could withstand a far greater pressure, as long as the air and other gases are at the same pressure as that of the atmosphere, and the

fluids are practically non-compressible. In other words, the internal pressure balances the external, and the body remains perfectly unconscious of the forces which are keeping it intact.

If a tin can be taken and water be boiled in it, the steam which escapes from the mouth of the tin gradually washes away all air from the interior of the vessel, and the tin is filled with an atmosphere of steam which is exerting exactly the same pressure upon the interior of the vessel that the air exerts on the exterior—the two forces balance, and the tin is in the same contented condition of neutrality that distinguishes our body. If now we cork the tin up air-tight whilst steam is still issuing from it, and remove the source of heat from under it, the tin will still remain unacted on so long as the steam remains uncondensed; but now pour some cold water over the outside of the tin—at once the steam condenses back to water, and the tin, being left with no internal support, is at once crushed up by the atmospheric pressure of 15 lbs. on the square inch, which it is totally unable to withstand.

All gases are elastic and can be compressed by pressure, the volume of a gas being inversely proportional to the pressure which is brought to bear upon it; that is to say, if the pressure on any given volume of gas is doubled the volume is halved, whilst if the pressure is halved the volume is doubled.

From this it is evident that the layers of air nearest the surface of the earth, having to bear the weight of the whole body of air above them, must of necessity be very dense, and rapidly decrease in density the higher one ascends; and it is this rapid decrease in the density as one ascends that enabled Perier to distinguish so great a difference in the

height of his column of mercury during the ascent of the Puy de Dôme.

If a cubic foot of air were taken at sea level and weighed, and another cubic foot collected a little less than three and a half miles (3·43) above the surface of the earth, we should find that it only weighed one-half as much, a fact which is expressed by saying that at that altitude the density of the air is only one-half what it is at sea level, or in other words, one-half the entire atmosphere is below a height of 3·43 miles from the earth's surface.

If the density of the atmosphere were the same throughout it would only extend to a height of between five and six miles; but the rapid diminution in density the higher one ascends shows that in all probability there is no definite limit, but that the last traces of atmosphere gradually shade away into space at a distance of certainly more than one hundred miles from the earth's surface. Wollaston attempted to fix the height of the atmosphere by the duration of twilight, which is dependent upon the refractive power of air.

If the earth had no atmosphere, there would be no intermediate period existing between broad daylight and darkness; the moment the sun set beyond the horizon the earth would be plunged into the darkness of night, whilst an equally sudden transition from dark to light would take place in the morning. The intermediate periods of twilight are caused by the fact that when a ray of light passes from one transparent substance through which it is travelling into another of different density, the ray is refracted, or bent from its original course, and the same thing takes place when a ray of light passes through a large body of gas which varies in density.

When the revolution of the earth on its axis causes the horizon to cut off our view of the sun, and so brings about what we call sunset, the direct rays of the sun still pass through the air, but above our heads, so that after the sun has set for the inhabitants of the plain, it can still be seen shining upon the sides of the hill above them. As the sun's rays pass from space into the attenuated gases which form the outer belt of the atmosphere, a bending of portions of the rays commences, and continues with the increase of density in the air as the earth is approached; so that although the direct rays of the sun can no longer reach the eye of the observer, these refracted rays still give a partial illumination of the earth for some time after the sun has set, and again appear to herald the approach of sunrise in the morning.

The principle of refraction can be easily shown experimentally by taking an empty basin and placing a penny in the bottom; now stand the basin on the table, and walk backwards from it until the side of the basin cuts off the penny from view—the side of the basin here playing the same part as the horizon. If now some one quietly pours some clear water into the basin, the penny will return to view, because the rays reflected from the coin, which would otherwise pass above the eye of the observer, are bent on passing from water to air, and so are brought down once more to the eye.

From the duration of twilight Wollaston came to the conclusion that the atmosphere extended in appreciable quantities to a height of forty to forty-five miles; but it has since been shown by Liai, Secchi, and others, that this distance is far too small, and, as before stated, it is probable that no actual limit exists; but from forty miles upwards there is

certainly not more air present than is to be found in the exhausted receiver of an air pump.

The birth of the history of our atmosphere may be justly said to have taken place in the middle of the seventeenth century, when that noble trinity of genius, Galileo, Torricelli, and Pascal, first showed that it had weight ; and slowly fact followed fact until its physical importance began to be fully realized, and also the fact that upon its presence depended many other phenomena, such as animal and vegetable life, radiation, the weather, transmission of sound, and many others which will be noticed as the subject leads to them.

Air was always looked upon by the old philosophers as an element, and when their views with regard to elements gradually underwent change, air was still regarded as such, and it was not until the latter end of the last century that it was finally proved not to be one.

During the last century lived Joseph Priestley, one of the most remarkable men this country has ever claimed as her own—a man so varied in his attainments, and so energetic in his life and work, that he published over one hundred different works, dealing with every conceivable subject, from theology to science ; but it was in the latter field that he especially shone, and the greatest achievement of his life was the discovery of the gas which we now call oxygen, and the fact that air was a mixture of this gas with four times its own volume of the inert gas called nitrogen.

Priestley lived in a day when a theory first propounded by the philosopher Stahl, and called the phlogistic theory, was raging amongst the savants of Europe, and foremost amongst the supporters of this theory was Priestley ; and so imbued was his mind with it that he was unable to see the drift and importance of the discoveries he had made. But in France

there lived and laboured at this time a man who had broken himself free from the trammels of the theories of those days, and who for some years had been working towards a true conception of chemical action, and the part played by the atmosphere, and only needed the discovery of oxygen by Priestley to put the keystone to the edifice, and it was to this master amongst scientific men that Priestley confided the discoveries he had made. This man was Lavoisier, whose theories and generalizations did more for science than perhaps the work of any one other man, of his, or any other time, and the only smirch on whose fair fame was, that he allowed the enthusiasm of his followers to claim for him discoveries to which other workers were entitled.

When Priestley told him of his discovery of oxygen, and the composite nature of air, Lavoisier was able to disentangle the important facts from the phlogistic jargon with which Priestley had clothed them, and he then made an experiment which has become historical, as proving for the first time beyond doubt, the fact that the air was not a simple elementary substance, but contained two perfectly distinct gases, oxygen and nitrogen.

Lavoisier placed in a long-necked retort about four ounces of mercury, and so arranged the apparatus that the air above the mercury in the retort should freely communicate with the air in a measured receiver, all contact with the outer air being prevented by standing the receiver in a vessel of mercury. He now heated the four ounces of mercury in the retort nearly to its boiling point, and kept it at this temperature for twelve days and twelve nights. At first no change took place, some of the mercury merely distilling up into the upper part of the apparatus and falling back again ; but presently some little red specks

began to appear on the surface of the mercury, and increased in number for several days, but at length ceased to form ; and after continuing the heating for a day or two longer in order to make sure that the action was completed, he allowed the whole apparatus to gradually cool down again to its original temperature.

Before starting the experiment he had carefully measured

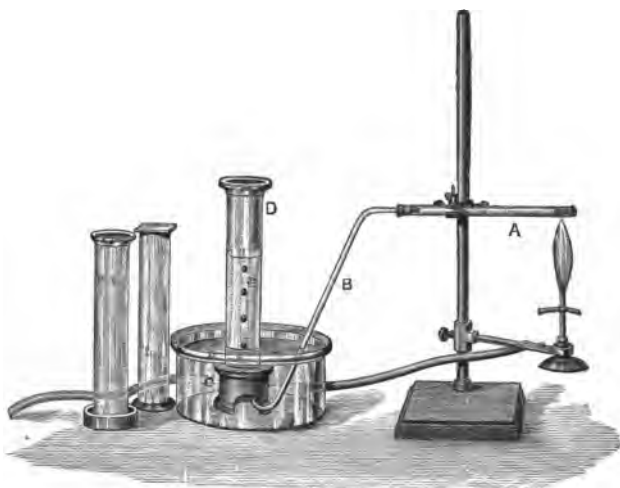


Fig. 2.

the air in the apparatus, which amounted to fifty cubic inches, and the first thing which he now noticed, was that of this forty-two cubic inches only remained, and that this residual gas had lost all the most characteristic properties of air—a taper plunged into it was at once extinguished, a mouse placed in it died after a few moments ; it would, in fact, neither support life nor combustion, and he recognized

it as a gas discovered some three years before by Rutherford, and now called nitrogen.

He then collected the red film formed on the surface of the mercury, which weighed forty-five grains, and heated the powder in a hard glass tube (Fig. 2) to a higher temperature than that at which it had been formed, when it again broke up, leaving behind metallic mercury, and yielding eight cubic inches of a gas which had to an exaggerated extent all the properties which the air had lost—a gas which he at once recognized as being the oxygen or “vital” air which Priestley had discovered in 1774. Even if Priestley had not discovered oxygen when he did, this honour would not have fallen to Lavoisier, for almost simultaneously with Priestley’s discovery this most important of the gases was isolated and described by Scheele in Sweden.

Although the researches of Priestley and Lavoisier showed conclusively that air was not an element, but contained the two gases oxygen and nitrogen, it had still to be shown whether these two gases were present in it in the state of mere mixture, or whether they were combined together as a definite chemical compound. When in mechanical mixture the distinctive properties of the substances present are retained, although often modified by the properties of the other constituents; but in a chemical compound the properties of the original factors entirely disappear, and are merged into new characteristics distinctive of the compound formed.

If iron filings and finely-powdered sulphur be mixed together a greenish-grey powder is formed, in which, by means of a microscope, the particles of sulphur and iron may be seen lying side by side, and from which the iron and sulphur may be recovered by mechanical means, such as acting

upon it with a magnet, which attracts and withdraws the iron, or by throwing it upon water, when the iron sinks more rapidly than the sulphur. Such a powder is called a mechanical mixture, and has all the properties of the substances composing it. If some of this mixture be heated a chemical action takes place, and the result is a black homogeneous mass in which no particles of sulphur or iron can be detected by the most powerful microscope; it is but slightly magnetic, and when thrown on water it sinks as a whole, and the iron and sulphur can only be again obtained from it by complicated chemical processes.

The chemical compound so formed has none of the properties of the sulphur or iron, but has acquired a new set of properties peculiar to itself. In determining whether a given substance be a compound or merely a mixture, a most important point to be ascertained is whether it varies in composition or not. A chemical compound is unalterable in composition, so that if a substance be a true compound it will always consist of the same elements combined in exactly the same proportions.

During the years that Priestley and Lavoisier were making their memorable experiments on the composition of air, the Hon. Henry Cavendish was also devoting his life to the cause of science, and these three men did much to make the close of the last century the most remarkable epoch in the history of both chemical and physical science.

Cavendish, who was one of the wealthiest men of his day, devoted his whole life and wealth to scientific research; and it is to him that we owe the first exact determination of the relation existing between the oxygen and nitrogen in air. In the year 1781 he made nearly four hundred determina-

tions of the composition of air, in order to find whether the amount of oxygen in it varied to any appreciable extent; and for this purpose he determined the amount present under every possible condition of weather; but no matter if the weather were fair and clear, or wet and foggy, no difference of which he could be certain could be detected.

He likewise experimented to see whether the air in London differed from the air in the country; but the results of all his experiments so closely agreed that the differences came well within the limit of experimental error found in the rough processes of analysis then in use; and he finally came to the conclusion that 100 volumes of air contain 20.83 parts by volume of oxygen. The remarkable constancy of his results naturally led him to the conclusion that air was a chemical compound, an opinion which was shared and strongly upheld in the succeeding years by Prout, Dobereiner, and Thomson, all of them maintaining that air was a chemical compound of one volume of oxygen with four volumes of nitrogen. Chemists were, however, not wanting to oppose this idea; and foremost among these was John Dalton, the father of our present system of chemical theory, who held that air was merely a mechanical mixture kept in a constant condition by certain natural forces; and he also propounded the theory, that because nitrogen is lighter than oxygen, there must be a larger proportion of oxygen present in the air near the earth's level than at an altitude from its surface. In this, however, he was wrong, for, as Gay-Lussac and Thénard afterwards showed, the air at a considerable height contains the two gases in exactly the same proportion as at sea level—a fact which they proved by going up in a balloon and collecting samples of air at a considerable height; and their results

have since been corroborated by Brunner, who analyzed air taken at the bottom and at the top of some of the highest of the Swiss mountains.

Before, however, this war of compound *versus* mixture could be brought to a satisfactory conclusion, it became necessary to institute newer and more accurate methods of analysis; and when this was done the researches of Bunsen, Leroy, and Regnault showed that the atmosphere shows sensible although very small variations in its composition—normal air containing 20·9 to 21 per cent. of oxygen, although under abnormal conditions, more especially in warm and swampy countries, the percentage sometimes falls as low as 20·3 per cent. ; and it was from the observation of these small discrepancies in composition, that in the middle of the present century the conclusion was finally arrived at, that the atmosphere was a mechanical mixture and not a chemical compound.

During the last forty years we have learnt much as to the action of traces of other gases which are also to be found in the atmosphere; but we may safely say that the true physical history of the atmosphere commenced with Torricelli's researches in 1643, whilst Priestley's discovery of oxygen awoke it into chemical life; and that the final acceptance of the fact that it was a mechanical mixture and not a chemical compound, marks the middle of the present century as the last important period of its history.

CHAPTER II.

THE CHIEF CONSTITUENTS OF THE ATMOSPHERE.

OXYGEN gas, the discovery of which cast such a lustre over the declining years of the last century, is one of the simple forms of matter which we designate by the term "element."

Any substance which defies the efforts of chemist and physicist to resolve it into any simpler form is called an element ; but we have to admit, that although we cannot break it up with the means at present at our disposal, it does not at all follow that at some future time it may not be decomposed ; for whenever new applications of force or new forms of energy have been discovered, they have generally resulted in the breaking up of some of the then elements ; and it was only whilst the present century was in its teens that Sir Humphrey Davy, by the application of galvanic electricity, showed the composite nature of several substances, which up to that time had been looked upon as simple forms of matter.

The old philosophers knew four elements—earth, air, fire, and water ; but with the last quarter of the eighteenth century the two survivors of this small band passed away, and now the known elements are close on seventy in number ;

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and from these all known forms of matter can be built up, or at any rate can be decomposed into them.

Very slight observation reveals the fact that these elements can be roughly subdivided into two classes, one of which, from the fact that its constituents possess lustre and the property of conducting heat and electricity, are looked upon as metals; whilst the second group, far smaller in number, are wanting in these characteristics, or possess them to a much smaller extent, and these are termed non-metals. It must, however, be clearly borne in mind that this division is purely one made by the chemist for his own convenience, and is not one authorized by the properties of the elements, which on close examination are found to shade away with such delicate gradations of characteristic functions, that no hard-and-fast line of demarcation can be drawn between the two classes.

It is also observable that the elements vary very greatly in their importance in nature, some pervading nearly all forms of matter, whilst others only exist as traces in rare minerals and in the waters of certain springs.

The general distribution of the elements in nature is roughly indicated by weight in the following table :—

Air.					
Nitrogen	...	...	...	...	76'9
Oxygen	...	...	...	...	23'1
					<u>100'0</u>
Water.					
Oxygen	...	...	...	...	88'8
Hydrogen	...	...	...	...	11'1
					<u>99'9</u>

THE SOLID CRUST OF THE GLOBE.

Oxygen	...	...	...	...	...	45·5
Silicon	...	...	...	...	...	29·4
Aluminium	...	...	...	...	...	8·2
Iron	...	...	...	...	...	6·3
Calcium	...	...	...	...	...	2·4
Magnesium	...	...	...	...	...	1·6
Sodium	...	...	...	...	...	2·5
Potassium	...	...	...	...	...	2·0
All the other elements	...	...	...	...	...	2·1
						<u>100·0</u>

—which shows that oxygen is not only the most important, but also the most abundant of the elements, constituting as it does more than one-half of known matter.

The greater part of the oxygen in nature exists in combination with other elements; indeed its power of combining with the other elements is so enormous that, until they are all satisfied, it is impossible for any to exist free in nature, and the oxygen in our atmosphere, which, with the exception of a small quantity dissolved in water, is the only free oxygen we know, is the residue left over after the other elements have combined with all they can; and although the amount of oxygen so present in the air amounts to 1,233,010 billions of tons, still it is only one two-millionth of the total oxygen, and had not this small fraction been left over in the creation of the world, neither animal nor vegetable life could have existed.

Oxygen, when pure, is a clear, colourless gas, devoid of all smell or taste; if a lighted taper be applied to a jar containing it, it is seen that the gas does not ignite, whilst if the taper be plunged into the gas the energy of its com-

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bustion increases to an enormous extent; and this latter property of urging on combustion is the one most characteristic of the gas, and any substance which will burn in air will burn with greatly increased vigour in pure oxygen, a fact which may be shown by many experiments.

A piece of charcoal, which under the most favourable conditions will only condescend to smoulder in ordinary air, burns with considerable rapidity and brilliancy in the oxygen, flinging out scintillations in every direction, as it rushes into chemical combination with the gas to form a compound of carbon and oxygen, called carbon dioxide or carbonic acid gas. In the same way sulphur and phosphorus, when ignited and plunged into the gas, burn with great increase of brilliancy, giving rise to compounds of sulphur and oxygen, and phosphorus and oxygen respectively. If the oxides so formed be dissolved in water they are found to yield solutions having a strong acrid taste, and the power of turning certain blue vegetable colouring matters to red, properties which are considered as being characteristic of the class of substances called acids; and noticing these results, Lavoisier not unnaturally came to the conclusion that oxygen was essential to the production of all acids, and hence named the gas oxygen, from the Greek *oxus*, an acid, and *gennao*, I produce; had he, however, continued his experiments further, he would have found that many substances which will not under ordinary conditions burn in air will burn in oxygen, and that amongst these are several of the metals.

A watch-spring which has had the temper taken out of it by heating, and has then been coiled into a spiral, can be made to burn in oxygen by attaching to the end of it a small piece of German tinder, the combustion of which in

the pure gas is sufficient to raise the temperature of the steel to a point at which it burns in oxygen with the greatest brilliancy, forming certain oxides of iron, which are flung out in a fused state in showers of bright sparks. Again, a tassel of thin zinc foil tipped with sulphur will, if the sulphur be ignited, burn fiercely in oxygen gas, giving a bright light, and leaving behind as the result of the combination the white compound of zinc and oxygen which we call oxide of zinc; now neither the oxide of zinc nor the oxide of iron, in combination with water, have any of those acid properties which characterize the solutions of the compounds formed by the combustion of substances of non-metallic properties, whilst if, instead of burning iron or zinc in oxygen, the rarer metals potassium and sodium had been made to combine with it, the oxides formed on solution in water would have had properties diametrically opposed to those of an acid, and would have been seen to have the property of turning back to blue the vegetable colouring matter which had been reddened by the acid. The name oxygen is therefore a misnomer, but any attempt to alter it would cause such confusion that it is better to retain the well-known name, wrong though it be, than face the chaos which an alteration in nomenclature would entail.

In all cases of combustion, the products formed weigh more than the substance burnt, and this is due to the oxygen which has combined with it. In Nature no such thing as loss or creation of matter occurs, although in many cases the products of the chemical changes taking place, being gaseous, escape our notice, as when a candle burns.

If, instead of allowing the candle to burn in the open air, it had been supported in a glass cylinder (A, Fig. 3), and the products of its combustion had been drawn by

means of the aspirator bottle (B) through tubes (c) (c), containing small fragments of sodic hydrate, which has the power of absorbing carbon dioxide and water-vapour (the gaseous compounds formed by the combustion of the wax of the candle), it could be shown that the products formed weighed more than the wax consumed.

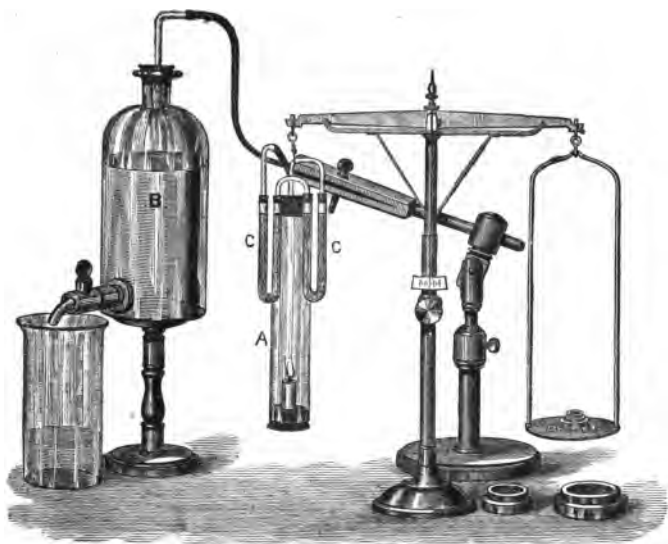


Fig. 3.

In scientific work the weights of all gases are compared with the lightest known gaseous element, hydrogen, and the number of times they are heavier than an equal volume of this gas is called their density; oxygen being volume for volume sixteen times heavier than hydrogen, its density is said to be sixteen.

The power which oxygen has of entering into vigorous chemical combination with every element, excepting perhaps fluorine, makes it the great factor in nearly every chemical form of natural action going on in our atmosphere, and it is oxygen which rings the changes in life and in decay, it is oxygen which carries on the processes of combustion on which we are dependent for the artificial production of heat and light.

Oxygen is but little soluble in water ; at ordinary temperatures 100 volumes of water barely dissolve three of the gas, but it is impossible to overrate the value of this small quantity ; not only does it support fish life, but it is absolutely necessary in order to rid water of noxious contaminations, which would otherwise render such a thing as a wholesome water unknown.

Some gases can be readily condensed into the state of a liquid by cold, pressure, or the two combined ; but until a quite recent period oxygen formed one of six gases which had resisted all efforts to condense them ; now, however, hydrogen is the only one remaining uncondensed, and we know that when a sufficiently low temperature can be obtained, pressure will cause this gas also to assume the liquid state. Oxygen was converted into a liquid by cooling it down to a temperature of -140° C., and at the same time subjecting it to a pressure of 320 atmospheres (320×15 lbs. on the square inch).

There are several methods by which oxygen can be obtained, and one would expect that inasmuch as it exists free in such enormous quantities in the atmosphere, this would be the best source from which to obtain it. This, however, can only be done by causing the oxygen to form a compound of easily decomposable nature with some other body, and

then to again decompose it, setting free the oxygen. In this way oxygen might be obtained from the air by the experiment described in the last chapter, by which Lavoisier first distinctly demonstrated the composition of air; but inasmuch as mercury is somewhat costly, and the process is a very long one, other and cheaper methods have been devised.

The most successful process for abstracting and recovering oxygen on a large scale from the air has so far proved to be the method known as the "Brin process," which consists of an alternate conversion of a substance called baric oxide into a still higher oxide by heating it in air, and subsequently decomposing it back to the original compound with evolution of the gas.

The possibility of doing this depends upon the fact that baric oxide, which contains 137 parts by weight of the metal barium, combined with sixteen parts by weight of oxygen, when heated in purified air under a slight pressure, absorbs sixteen parts more oxygen, forming what is called baric peroxide; and then if the pressure be diminished or the temperature still further raised, again gives off the extra oxygen it has taken up, returning once more to the condition of baric oxide, and ready to be utilized once more for the absorption of more oxygen.

Another and rather more complex process of the same kind is to heat a compound called sodic manganate in a current of steam, when it breaks up into a mixture of caustic soda and sesquioxide of manganese, at the same time liberating oxygen which may be collected; whilst if the steam be now stopped, and air be passed over the mixture, the original sodic manganate is again formed, and so by alternating currents of steam and air an intermittent supply

of oxygen can be obtained. Certain practical difficulties have, however, prevented this process ever becoming a successful method of obtaining oxygen cheaply from the atmosphere, although from time to time the solution of the difficulties have been somewhat prematurely announced. Neither of these processes, however, is convenient for making the gas on a small experimental scale, and in the laboratory the usual method employed is to decompose a salt called potassic chlorate by heat.

Potassic chlorate contains 39 parts by weight of the metal potassium, which occurs in combination in the ashes left on burning most plants, with 35.5 parts by weight of chlorine, one of the gaseous elements, and no less than 48 parts by weight of oxygen. On heating this salt it first fuses to a liquid, which then commences to boil, giving off oxygen in abundance, and leaving the potassium and chlorine combined together as potassic chloride.

The operation is generally performed in a small flask or tube, the open end of which is closed gas-tight by a cork through which a tube passes bent so as to lead the gas as it is evolved below the surface of water contained in a vessel called a pneumatic trough, so arranged that the escaping gas bubbles up from the end of the tube, and passing up through a hole in a shelf below the surface of the water, enters an inverted receiver or bottle full of water standing on the shelf, and, displacing the water, is collected free from contact with air.

In collecting any gas, the first portions which come from the end of the tube are allowed to freely escape, as, being contaminated with the air present originally in the generating vessel, they would render the collected gas impure.

The liberation of the oxygen from potassic chlorate can

be rendered much more rapid, and can also be effected at a lower temperature, if a small quantity of the mineral pyrolusite, or black oxide of manganese, be mixed with it in the state of fine powder ; but what is gained in time is lost in purity, as the gas so made is nearly always found to be contaminated with small traces of the gas chlorine, which renders the oxygen so made unfit for any but the roughest experiments.

The relative rates at which the gas is evolved from the

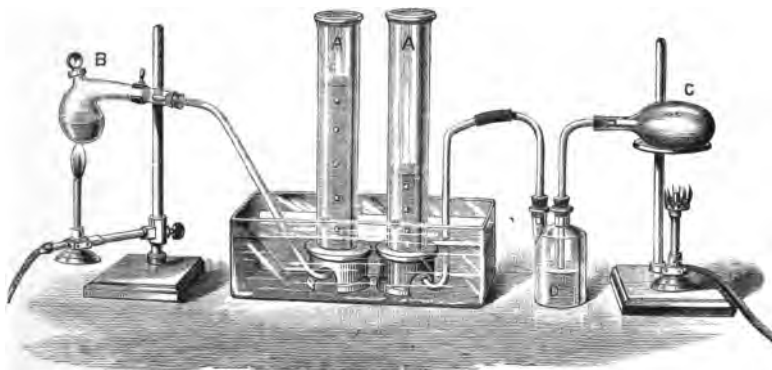


Fig. 4.

chlorate alone, and from chlorate mixed with the manganic peroxide, may be shown by performing the operations side by side (Fig. 4) and collecting the gas formed in two cylinders of equal size (A A). The chlorate is heated in the retort (B) fitted with a delivery tube leading under water in the pneumatic trough, whilst the mixture of chlorate and manganic dioxide is heated in the Florence flask (C), and the gas, before collecting, is washed by passing through water in the two-necked bottle (D).

Oxygen gas may be recognized roughly by its characteristic property of rekindling a glowing spark on the end of a splint of wood into a flame ; but too much reliance must not be placed on this test, as the same property is possessed by nitrogen monoxide, sometimes called laughing-gas, which is the nitrous oxide of the dentist.

These two gases, however, can be distinguished the one from the other by bringing them both in contact with another oxide of nitrogen, called nitrogen dioxide, which turns reddish-brown in contact with oxygen, but not in contact with laughing-gas. Oxygen may also be recognized by potassic pyrogallate turning dark-brown when brought in contact with it, and absorbing it readily, a property which is utilized in analyzing mixtures of gases containing oxygen.

The facts that nitrogen dioxide becomes a reddish-brown gas when brought in contact with air, and that potassic pyrogallate turns to a dark-brown compound under the same conditions, are proofs that the oxygen in the atmosphere is present there in the free state and not in combination, as these changes only take place when the gas is uncombined, and do not occur with compounds of oxygen.

A modification of oxygen occurs in small traces in the atmosphere, and is known by the name of ozone.

The ancients noticed that whenever buildings or trees were struck by lightning, a peculiar odour was to be observed for some time in the near neighbourhood, and conceiving that lightning was a manifestation of demoniacal power, they came to look upon this particular smell as a personal attribute of the Evil One himself.

Towards the end of the last century Van Marum noticed that the same smell accompanied the discharge of electricity

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from the poles of his big electrical machine, and in the middle of this century the Swiss chemist Schonbein showed conclusively that this peculiar and pungent odour was caused by the electrical discharge converting some of the oxygen present in the air into an extremely active modification, which, however, could be reconverted into ordinary oxygen by the action of heat.

When an element exists in two or more forms which are physically dissimilar, although chemically identical, these forms are said to be allotropic modifications of that element.

One of the best examples of this peculiar property is to be found in the element carbon, which exists in two perfectly pure natural forms—as the lustrous gem, the diamond, and as graphite or black lead; the one almost the hardest substance known in nature, with its wonderful power of refracting light, whilst the other is so soft that on drawing it across a piece of paper some of it rubs off and leaves a black mark, and it is for this reason that it is used to form the core of pencils. The diamond and graphite, as they can both be proved to be chemically identical, are called allotropic modifications of the element carbon.

Oxygen may be converted into ozone by causing a slow stream of the gas to pass between surfaces charged with opposite kinds of electricity. This may be effected in the apparatus shown in Fig. 5. A slow stream of oxygen is passed through the cylinder (A) from a reservoir of the gas, and a little water at the bottom of the cylinder allows the rate at which it is passing to be seen. The gas then passes on through the ozonizing tube (B), in the centre of which is a tube filled with mercury, and connected with one pole of the coil (D), the other pole being in connection with

water in the cylinder (c) which surrounds the ozonizing tube. In this way the oxygen is made to pass through a contracted space, through which a brush discharge is passing from the mercury to the water, with the result that some of the oxygen is converted into ozone, and may be collected by downward displacement.

Also it is found to be produced in the air by contact with substances which are undergoing slow oxidation in the

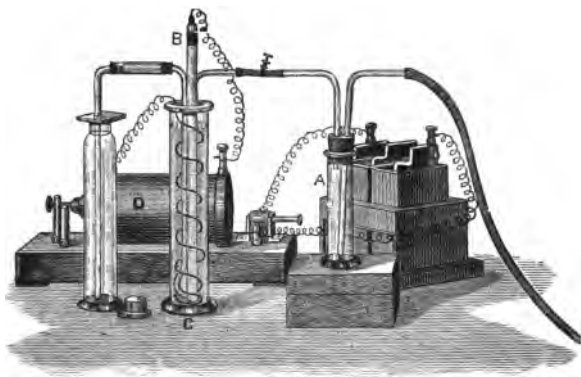


Fig. 5.

presence of moisture. If a stick of phosphorus which has been scraped clean under water is placed on its side at the bottom of a flask of air, with just enough water at the bottom to half cover the phosphorus, it slowly oxidizes at the expense of some of the oxygen of the air, whilst ozone is at the same time produced, and may be recognized by characteristic tests.

When water is decomposed by passing a galvanic current through it, it is resolved into its constituents, oxygen and

CHIEF CONSTITUENTS OF THE ATMOSPHERE. 31

hydrogen, and some of the oxygen so liberated is converted into ozone.

Ozone may be readily recognized by its odour, which is so pungent that it is said to be easily perceived when there is only one volume present in $2\frac{1}{2}$ million volumes of air, and the smell may sometimes be detected in the country and in sea air.

The most usual test for detecting traces of ozone in air is to expose strips of blotting-paper moistened with a mixture of potassic iodide and starch, when, if any ozone be present, it decomposes the iodide, combining with potassium to form an oxide, whilst the iodine combines with the starch, forming a dark-blue compound; this test, however, is not perfectly reliable, as there are sometimes traces of other gases present in the air which would give the same result; and in order to make quite sure that the turning blue of the paper is due to this cause, it is necessary to use a second test, which consists of soaking red litmus paper in a very dilute solution of potassic iodide, when the conversion of the iodide into oxide causes an alkaline reaction, and turns the red paper to blue.

The most characteristic properties of ozone are dependent upon the strong oxidizing action which it has, and which causes it to attack many substances which are not affected by oxygen itself; it tarnishes mercury, and attacks india-rubber with great rapidity, and in nature tends to destroy organic germs and impurities which may be present in the air; and for this reason, although it may be frequently detected in country air where there are few causes to use it up, it is rarely if ever found in the air of large towns, where organic germs and products of imperfect combustion rapidly use up all traces of it.

In all cases of oxidation by ozone, there is exactly the same volume of oxygen left free after the action as there was of ozone before, which shows that the ozone is in reality a condensed form of oxygen, and it is this compression of a larger number of atoms into the molecule of the gas which gives it its active properties.

Although small traces of ozone in the air constitute a powerful agent for the purification of the atmosphere from waste organic matter, in larger quantities it acts as a violent poison, causing intense irritation to the eyes and nose, and finally proving fatal. Ozone is slowly decomposed into oxygen in moist air at the temperature of boiling water, whilst above 230° C. it rapidly breaks up. When a large volume of gas rich in ozone is looked through, it is seen to have a distinct blue tint, and it is supposed that the blue colour of the sky is due to this cause.

Nitrogen, the second great constituent of our atmosphere, was first discovered by the chemist Rutherford in 1772, and is as remarkable for its inert character as oxygen is for its activity. It constitutes 79.1 per cent. of the atmosphere by volume, and 76.9 per cent. by weight, and also occurs in nitric acid and the nitrates, ammonia, and many forms of animal and vegetable matter. The fact that nitrogen is chiefly found in nature in the free or elementary condition, shows at once that its power of combining with other substances must be of a very low order. It exists in the tissues of animals and plants, and is essential to the existence of all forms of life.

Nitrogen when uncombined is not itself a poison, although it destroys life by keeping away the oxygen from the lungs of any living thing plunged into an atmosphere of it; but, curiously enough, it is a constituent of nearly all the most

poisonous organic compounds, such as strychnine, brucine, and Prussic acid. Nitrogen may be prepared from the atmosphere by removing the oxygen with which it is mixed. This can be done by burning anything in a confined volume of air which will combine with the oxygen present, and form an easily removable compound ; the most convenient substance to employ is undoubtedly phosphorus, the affinity of which for oxygen is so great that it may be relied on to continue burning until the last trace of oxygen is removed ; in combining with the phosphorus the oxygen forms a white solid known as phosphorus pentoxide, which is very soluble in water ; so that if the experiment be performed in a volume of air confined over water, the phosphorus being floated in a small capsule of some non-inflammable substance, the pentoxide as it is formed slowly dissolves in water, which rises in the vessel to occupy the space originally taken up by the oxygen in the air, and the nitrogen is left in a sufficiently pure condition for all ordinary experimental work ; if wanted absolutely pure, it has to be made by decomposing the salt called ammoniac nitrate, which under the influence of heat breaks up into nitrogen and water.

Nitrogen neither supports combustion nor does it itself burn in the ordinary acceptance of the term, but inasmuch as it forms no less than five compounds with oxygen, it is evident that this phenomenon is due to our inability to produce a sufficiently high temperature to bring about a direct combination ; that this is the true explanation is manifest from the fact, that compounds of oxygen and nitrogen are to be found in the atmosphere after thunderstorms or other electrical disturbances, whilst an electric spark passed for some time through a confined volume of air soon causes it to assume a brown tint from

the formation of some compounds of nitrogen and oxygen, so that from the temperature of the electric spark it is evident that the nitrogen becomes inflammable.

Nitrogen gas can be collected over water, as it is only very sparingly soluble, 100 volumes of water only dissolving $1\frac{1}{2}$ volumes of gas at ordinary temperatures. It is a tasteless, odourless, and colourless gas, which, although so inert in its behaviour towards most substances, combines with some of the rarer elements, such as tungsten and titanium, with such energy that they become incandescent when thrown into the pure gas.

In comparing the weights of gases, hydrogen, which is the lightest gas known, is always taken as unity, and the weight of equal volumes of other gases measured off at the same temperature and pressure and compared with hydrogen, in order to give what is called the density of the gas, which expresses how many times it is heavier volume for volume than hydrogen. Oxygen is found to have a density of 16, whilst nitrogen is 14, and the atmospheric mixture of the two gases is 14.47 times heavier than an equal volume of the standard gas.

CHAPTER III.

THE MINOR CONSTITUENTS OF THE ATMOSPHERE.

It is usual to speak of all gases besides oxygen and nitrogen which are present in the atmosphere as impurities, but this is manifestly incorrect, as there are at least three compounds present to a greater or less extent, which are absolutely essential for the carrying out of nature's laws, and which do not become real impurities unless they rise above a certain limit.

These compounds are carbon dioxide, water-vapour, ammonia, and nitric acid; the water-vapour being almost as essential as oxygen and nitrogen for animal life and comfort, whilst the others are needed for certain phases of plant life.

Inasmuch as the atmosphere entirely enfolds the world in a vast aëriform mantle, it is evident that all gaseous impurities escaping from the surface of the earth must find their way into it, and we can form a very sound judgment as to which of these constitute the real impurities, and which are only impurities after a certain limit is reached, by noticing their distribution in nature. The impurities pure and simple only exist at those spots where the causes which give rise to them are to be found, whilst the natural impurities are equally distributed throughout the atmosphere.

Carbon dioxide, or carbonic acid gas, as it was more commonly called, was discovered in the seventeenth century, and its properties fully investigated towards the end of last century ; and this gas constitutes one of the most universally present constituents of the atmosphere, samples of air collected in every part of the world showing it to be present to the extent of about four volumes in 10,000 of air.

All forms of fuel contain, as an essential part, the element carbon, and whenever this carbon, or any substance containing it, burns in air it does so because the carbon enters into combination with the oxygen, and the resulting product is carbon dioxide, a clear colourless gas, containing twelve parts by weight of carbon combined with thirty-two by weight of oxygen.

Carbon dioxide exists in combination in nature in enormous quantities, forming the compounds called carbonates, which constitute a large proportion of the crust of the globe, chalk, limestone, marble, and Iceland spar, all of which are forms of calcic carbonate, whilst the carbonates of magnesium and iron are scarcely less abundant.

The gas is also found issuing in large volumes from the earth, especially in volcanic districts, and, under certain circumstances, accumulates in such quantities as to render certain valleys and caves fatal to animal life, as in the Poison Valley of Java, where the gas issues in such rapidity from fissures in the rocks that it cannot be dissipated as quickly as it emerges, and being irrespirable, overcomes and suffocates any living thing which ventures within the slopes of that deadly region.

Carbon dioxide can be prepared from calcic carbonate by heating it when it decomposes, carbon dioxide being evolved, and calcic oxide or quicklime left behind, an

operation performed in the so-called lime-kiln. For laboratory use, however, it is obtained by adding dilute hydrochloric acid to one of the denser forms of calcic carbonate, such as marble or limestone, contained in a generating flask, so arranged that the escaping gas can be led to the pneumatic trough and collected in the usual way (Fig. 6).

The hydrochloric acid acts upon the calcic carbonate forming calcic chloride, water, and carbon dioxide, the

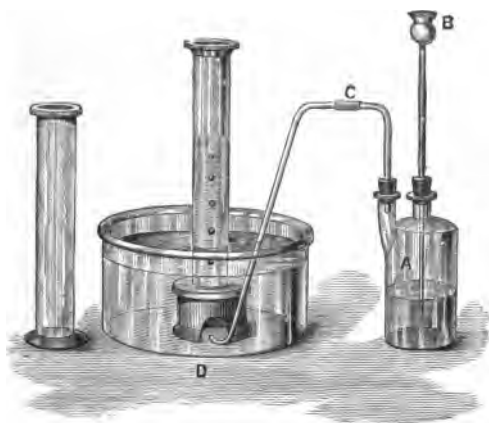


Fig. 6.

latter escaping, whilst the two former remain behind in the generating vessel.

Carbon dioxide has a faintly acidulous taste and smell, and is characterized by neither supporting life nor combustion. It is a very heavy gas, its density, that is the ratio of its weight, as compared with an equal volume of hydrogen, being twenty-two. It is soluble in water, but the volume so dissolved depends largely upon temperature

and pressure; water dissolves its own volume of the gas under all conditions, and inasmuch as gas contracts with cold, and also occupies a diminished volume under the influence of pressure, it is manifest that water must dissolve a far greater quantity at a low temperature and under a high pressure than under ordinary conditions.

Water under ordinary conditions of temperature and pressure dissolves its own volume of gas, that is to say, at 15° C., and with the barometer standing at thirty inches (760 mm.) a pint of water will dissolve a pint of the gas; but a change either in the temperature of the water or in the pressure of the atmosphere will be accompanied by a change in the quantity of gas dissolved; so that if the water were cooled down to 0° C., the pint of water, instead of dissolving one pint of the gas, would dissolve nearly $1\frac{3}{4}$ pints, and any increase of the atmospheric pressure, shown by a rise in the barometer, would also cause an increased absorption of the gas; and if the water be then brought to its initial temperature of 15° C., or if the extra pressure were removed from its surface, the amount of carbonic acid, over and above the pint it can dissolve under those conditions, once more escapes, and causes the water to effervesce.

As has been pointed out, carbon dioxide exists in enormous quantities in the earth, and it often happens that water, in permeating through the earth, collects in subterranean caverns full of the gas, and as it accumulates causes a pressure under which the water becomes saturated with gas; and this solution finding its way back to the surface, and escaping as a spring, effervesces and gives up the surplus gas on coming once more under ordinary atmospheric pressure, and so gives rise to the natural effe-

vescing waters, which being in great demand as table waters gave rise to the idea of making them artificially, and so sprang up the aërated water trade. Joseph Priestley may be looked upon as the founder of the mineral water industry, as in his early life he examined the properties of the gas given off during fermentation (carbon dioxide), and noticed the fact that a larger quantity was dissolved by water when under pressure than when under ordinary conditions, and

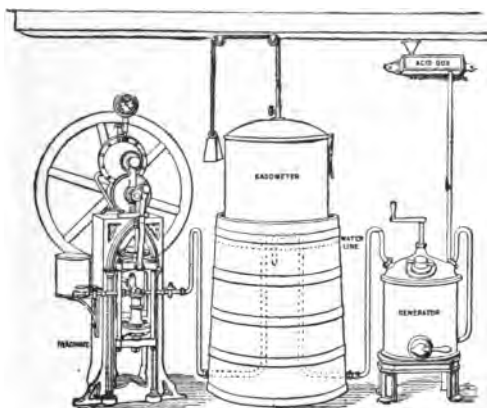


Fig. 7.

that water so treated had the property of sparkling and being more pleasant; indeed in one of his many pamphlets he suggests that water might with profit be so treated.

In the manufacture of aërated waters, water is first rendered slightly saline by the addition of a few grains per gallon of soda, salt, potash or lithia, according to the character of the water to be made, and is then saturated with carbon dioxide pumped into it by means of a force

pump, the liquid being then corked up and the cork wired in, so keeping up the pressure, and keeping the gas in solution until required for drinking.

The machines in use for saturating water with carbon dioxide are numerous, but the principle is nearly all the same (Fig. 7).

Carbon dioxide is generated by acting upon some carbonate, generally carbonate of lime in the form of whiting, with dilute sulphuric acid, and the gas so generated is led into a gasometer, after having been washed by passing through water; the gasometer is connected with a gun-metal pump, which also is connected with a reservoir containing pure water, in which about one ounce of bicarbonate of soda has been dissolved to every gallon of water; this solution and the carbon dioxide are forced together by means of a pump into a strong condenser lined with tin, and in which the gas and liquid are agitated together by means of revolving arms fixed on a spindle and driven at high speed, and it is in this condenser that the water becomes highly impregnated with the gas under pressure.

The effervescence of champagne, the old stone bottle ginger-beer, and other fermented drinks, is also due to the escape of carbon dioxide from solution, but in these cases it is formed by actions going on in the liquids themselves, and is not artificially pumped into solution. All processes of fermentation yield carbon dioxide, so that if a liquid which is still fermenting be corked up in a bottle the action continues, and the carbon dioxide as it is liberated, being unable to escape, creates for itself a pressure under which it is dissolved, only again to escape when the pressure is removed by the taking out of the cork.

When carbon dioxide dissolves in water it is supposed to

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combine with the water to form a compound with it called carbonic acid, but this body is so easily decomposed that it is impossible to isolate it, and so its composition has never been directly proved; but it is evident that, when water saturated with carbon dioxide is allowed to stand, some change takes place, for if the pressure be taken off immediately after it has been saturated, the gas at once escapes in bubbles so minute and abundant that they make the liquid look quite turbid and milky; whilst if the solution has stood for a short time, on removing the pressure the gas escapes, but in large bubbles and much more slowly, and the effervescence instead of being all over in a few minutes continues for a considerable time, which looks as if on standing the carbonic acid had formed, and that its decomposition resulted in the slower generation of gas.

When carbon dioxide is cooled to near the freezing point, and is then subjected to a pressure of 36 atmospheres—*i. e.* 36×15 lbs. on the square inch, it is converted into a clear colourless liquid, and can be kept in this condition in a vessel sufficiently strong to stand this pressure; if, however, the pressure be suddenly removed, the liquid at once assumes the gaseous state again, and in doing so produces great cold.

Change of state always produces change of temperature, and when a gas becomes a liquid heat is given out; but when the liquid again assumes the gaseous state, as much heat is absorbed as was given out during its liquefaction, and the rapid conversion of the liquid carbon dioxide into the gaseous state results in the absorption of so much heat that some of the liquid carbon dioxide becomes frozen into the solid state, and the cold produced is not far short of -100° C.

The solid may be formed by condensing the gas by cold and pressure in an iron cylinder (Fig. 8), and then by opening a valve the liquid carbon dioxide by its own pressure is driven up a tube which goes to the bottom of the cylinder and escapes into a brass box ; here under ordinary atmo-



Fig. 8.

spheric pressure the liquid rapidly assumes the gaseous state, and abstracts heat from the surrounding objects, and so reduces the temperature that some of it freezes to a solid, the gas escaping through the wooden handles of the box, which are hollow ; on opening the box the solid carbon dioxide is found as a white substance like snow.

This solid carbon dioxide when placed upon the hand merely produces a sensation of cold, because the slow escape of gas from its surface forms a cushion between it and the skin, but when pressed down so as to bring it in contact it gives the sensation of burning and forms blisters.

By mixing this solid carbon dioxide with ether the gas is

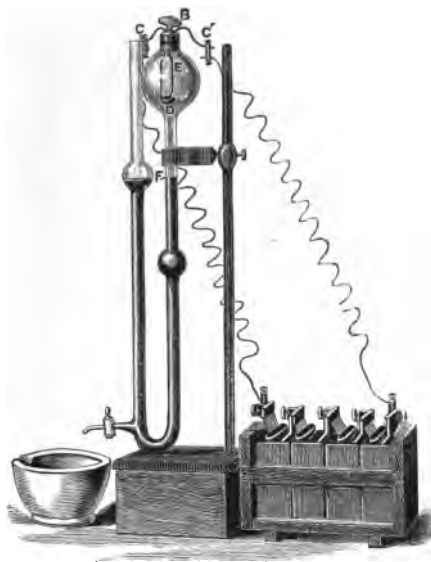


Fig. 9.

caused to come off from it with great rapidity, and the increase of rate in change of state causes an increase in the intensity of cold formed, so that a mixture of solid carbon dioxide and ether forms one of our most powerful freezing mixtures and gives a temperature of below -100°C .

All freezing mixtures depend upon the absorption of heat

during change of state. Some solids which dissolve very rapidly, such as ammoniac nitrate, will when dissolved in water absorb enough heat to convert water into ice; whilst in other cases the solution of Glauber's salts in hydrochloric acid, or the conversion of ice into water by mixing the ice with salt, and so causing its rapid liquefaction, are used in order to produce a considerable fall in temperature.

Carbon dioxide contains its own volume of oxygen combined with carbon. This may be shown by burning carbon in oxygen confined over mercury in the apparatus (Fig. 9).

A bulb tube is closed by a glass stopper (B), through which pass a small deflagrating spoon (D) and a thick copper wire (E); these are joined by a piece of thin platinum wire, which is coiled round a small lump of charcoal in the spoon (D). The bulb having been filled with oxygen, the stopper is closed, and the height of the mercury at (F) having been noted, a current from a battery is passed through the connections (C C), and heats the thin platinum wire to redness, igniting the charcoal, which burns in the oxygen, forming carbon dioxide. The heat generated by the combustion expands the gas and depresses the mercury, but on allowing the gas and apparatus to cool down to its original temperature, the mercury again rises to the point (F), showing that no change in volume has taken place.

Carbon dioxide can also be proved to contain carbon by passing the well-dried gas over a piece of the metal potassium heated to the melting point in a thin glass tube (Fig. 10).

The carbon dioxide is generated from marble and hydrochloric acid, and is then passed through a wash-bottle and calcic chloride tube in order to dry it. The potassium is placed in a drawn-out test-tube, and heated by a Bunsen flame, when it burns with a red glow, at the expense of the

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oxygen contained in the carbon dioxide, and deposits carbon as a black mass.

Carbon dioxide, as has already been pointed out, exists in the atmosphere in the proportion of four parts in 10,000, and unless it rises above this quantity it is not an impurity.

The second of the so-called natural impurities in air is water vapour, and this may be looked upon as forming really a separate atmosphere, as if there were no air the earth would still be surrounded with an atmosphere of

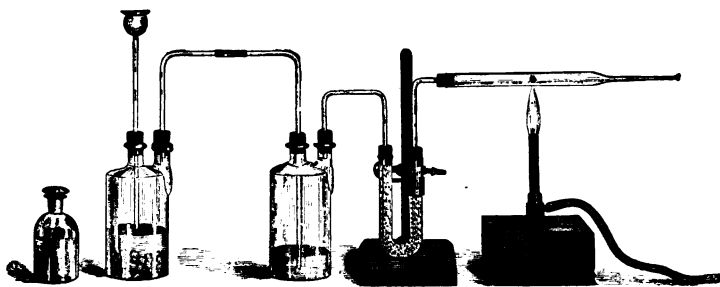


Fig. 10.

aqueous vapour, which fluctuates in quantity with every change in temperature. At 0° C. one cubic foot of such an aqueous atmosphere would only contain about one-fifteenth of the weight of water that it would at 80° C., so that although the density of the aqueous atmosphere would be very considerable at the tropics, it would be practically nil at the poles. The formation of water-vapour is due to the fact that water evaporates at all temperatures, so that a slow escape of water-vapour is always taking place from the face of the earth; and although the air retards the

formation of water-vapour, it does not prevent it, and at any given temperature the same amount of water would evaporate into a given space whether it be filled with air or a perfect vacuum. This phenomenon is due to what is called the tension of aqueous vapour, a property of water which will be fully discussed when considering the formation of rain. It is usual in speaking of the water-vapour to talk of its being suspended in the atmosphere, but this is evidently not correct; and although the water-vapour deposits from the atmosphere either in the form of fog, rain, or dew when any sudden fall of temperature takes place, still precisely the same thing would happen, only with greater rapidity, if no air had been present; any cooling of the air, and therefore of the water-vapour which is contained in the same space, causes a partial condensation of the latter, so that when the air is cold there is far less water-vapour present than when it is hot.

It is impossible to overrate the importance of water-vapour in our atmosphere to animal and vegetable life, as the amount of water present in the atmosphere at any particular temperature regulates the rate at which water held in the tissues of plants and animals evaporates from their surfaces into the air. The solid wood which forms the trunk of the tree contains from 20 to 50 per cent. of moisture, whilst the fruit and vegetables contain far more, as is shown in the following table:—

Potatoes	75	per cent. water.
Plums	75	" " "
Apples	80	" " "
Carrots	83	" " "
Turnips	90	" " "
Cucumbers	97	" " "

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whilst the human body itself contains about four-fifths of its total weight as water ; whilst in some of the lower forms of animal life, such as the medusæ, at least 999 parts in 1000 consist of water. Water, therefore, is the chief material of which all organized structures are built up, and if there were no water-vapour present in the atmosphere it would be impossible for the system to supply the surface of the body with water at a sufficient rate to replace the moisture withdrawn by rapid evaporation.

It is a well-known fact that plants rapidly droop and die in rooms which are heated by certain forms of stove, which by heating the air, and so giving it a greater capacity for water-vapour, cause an increase of evaporation from the surface of vegetation exposed to its drying influence ; such drooping cannot be checked by watering the soil in which the plant is growing, as it is unable to draw the water up from the soil and assimilate it with sufficient rapidity to supply the amount lost from the surface of its leaves ; the drooping, however, may be checked by sponging the leaves of the plant, which checks the withdrawal of the moisture from its tissues. The same action causes to a great extent the feeling of discomfort experienced by persons inhabiting rooms heated by such systems ; as what is true of the plant is equally true of the human being ; where you see the delicate vegetable organism suffering from the condition of the atmosphere in which it is placed, you may be quite sure that the same deleterious influences are affecting your own health, although probably to a less noticeable extent.

It is evident that the moisture contained in the air is liable to very extensive changes in quantity, as not only is it affected by temperature, but also by the presence or absence of exposed surfaces of water and the configuration of the

land. One cubic meter of air will at different temperatures take up the following quantities of water—

—10° C. = 2·284 grams water.	25° C. = 22·843 grams water.
0° C. = 4·871 „ „	30° C. = 30·095 „ „
10° C. = 9·962 „ „	35° C. = 39·252 „ „
20° C. = 17·157 „ „	40° C. = 50·700 „ „

If air saturated at any particular temperature be cooled, the amount of water-vapour over and above that which it can hold at the lower temperature is deposited; so that if a cubic mile of air saturated with water-vapour at 35° C. were to be cooled down to the freezing point, upwards of 140,000 tons of water would be deposited as rain, fog, or snow. It, however, very rarely happens that the air is very completely saturated with water-vapour even over the surface of the sea, and the amount of moisture present also rarely sinks below one-tenth of the saturating quantity.

The amount of moisture present in air can be determined by causing a slow current of air to flow through tubes containing hygroscopic substances, which have the power of taking up and absorbing water, when by noticing the increase in weight which takes place, and knowing the volume of air which has been passed through, it is easy to calculate the percentage of moisture present; it is more usual, however, to determine the moisture by an apparatus called the “hygrometer”; of these perhaps the most used is what is known as Daniel’s hygrometer—it consists of a bent tube with a globe at each end, and is partly filled with ether, the rest of the space in the tube being filled with the vapour of ether, all air having been expelled; one globe is made of either blackened or silvered glass, and contains a thermometer, whilst the second globe is covered with muslin. In using

this instrument the ether is passed into the blackened bulb containing the thermometer, whilst the muslin surrounding the second bulb is moistened with ether, the rapid evaporation of which causes a condensation of some of the ether vapour in the interior of the apparatus, which in turn produces evaporation from the surface of the ether in the blackened bulb. As has been already shown, evaporation is always accompanied by absorption of heat, so that the blackened bulb gradually becomes colder and colder, and the moment is soon reached when the air in contact with it begins to deposit dew upon its surface. When this point is reached the temperature shown by the thermometer in its interior is read, and from the amount of fall of temperature necessary to induce deposition of moisture from the atmosphere, the amount of saturation is determined.

The last two constituents, of which traces are always to be found in the atmosphere, and which are essential to the carrying-on of Nature's functions, are ammonia and nitric acid, which, however, exist in such excessively minute traces as to be only detected by the most delicate chemical means; and yet, small as are the proportions in which these substances exist, they play a most important part in the growth of vegetation, as it is from them, to a great extent, that plants during their natural growth derive the nitrogen which is requisite for the formation of their seed and other portions of their structure.

Ammonia is next to hydrogen one of the lightest of the gases, and is characterized by its intensely pungent odour; it is a perfectly colourless gas, and does not support combustion, nor does it burn under ordinary conditions. So pungent is the odour of this gas that it would be impossible for it to be present in any considerable

quantity in the atmosphere, and the quantity rarely exceeds $3\frac{1}{2}$ parts in 10,000,000 of air, a quantity which one would imagine would be totally inadequate to supply the wants of growing vegetation; but the gas is so intensely soluble in water, that one pint will dissolve from 700 to 1,000 times its own volume of the gas, according to the temperature; and the result of this is, that every shower which falls washes the air free from the traces of this compound, bearing it down in solution to the plants which need it for their fructification.

Ammonia gas is a compound containing fourteen parts by weight of the element nitrogen, combined with three parts by weight of hydrogen, and it is formed in nature by the decomposition of nitrogenous organic matter, of which the waste products of life largely consist. If, for instance, horn is subjected to destructive distillation, a pungent-smelling liquid, called oil of hartshorn, distils over, which is practically a solution of ammonia, formed from the nitrogenized organic matter the horn; it is also produced in large quantities during the destructive distillation of coal for the production of coal-gas, and it is from this source that commercially the ammonia and ammonium salts used in this country are produced. If ammonia gas be brought into contact with any acid, the characteristic properties of the acid disappear, and a new compound called a salt is produced; if in this way ammonia gas and hydrochloric acid gas be allowed to come in contact, a white solid called sal ammoniac, or ammoniac chloride, is formed, and from this compound the ammonia can once more be obtained by heating it with lime, a decomposition of which we take advantage when we want to prepare the gas for experimental purposes. Volume for volume ammonia gas is 8.5 times heavier than our standard gas hydrogen, and

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it is therefore lighter than air in the proportion of 8·5 to 14·47. Nitric acid, of which also minute traces exist, is partly formed by the oxidation in loamy soil of the ammonia evolved from decomposing nitrogenized organic matter, and also partly from the direct combination of small quantities of nitrogen and oxygen in the atmosphere during electrical disturbances, and the subsequent solution of the oxides of nitrogen so formed by rain. Nitric acid, like ammonia, aids in small traces the fertilization of various forms of vegetation.

The gaseous elements and compounds already enumerated are the true constituents of the atmosphere, and its composition may be taken as being as follows—

COMPOSITION OF THE ATMOSPHERE.

Oxygen	...	...	...	...	20.61
Nitrogen	...	...	...	...	77.95
Carbon dioxide	...	...	...	...	.04
Aqueous Vapour	...	...	...	...	1.40
Nitric Acid	} traces				
Ammonia					
Carburetted hydrogen					
					<hr/> 100.00

COMPOSITION OF THE ATMOSPHERE IN TONS.

Oxygen	...	...	1,233,010	billions of tons.
Nitrogen	...	...	3,994,593	" "
Carbon dioxide	...	...	5,287	" "
Aqueous Vapour	...	...	54,460	" "

Samples of air taken in every part of the world, and at all attainable altitudes, show these gases to be always present, and unless some specific cause exists for the variation, they are present in quantities approximating to the number given ; but should the quantities of carbon dioxide, water-vapour, ammonia, or nitric acid rise far above these amounts, then they cease to be necessary constituents of the atmosphere and become impurities. For instance, if one goes into a stable the nose at once detects a considerable quantity of ammonia, which is being evolved from the decomposing urine present, and in such air the amount of this gas would far exceed the $3\frac{1}{2}$ parts in 10,000,000 in which it ordinarily exists, and it would now be an impurity ; in the same way in an ill-ventilated room, it is no uncommon thing to find ten parts of carbon dioxide, instead of the normal four in 10,000 of air, and not only would this constitute an impurity, but would be actively detrimental to health and comfort.

CHAPTER IV.

THE LOCAL IMPURITIES IN THE ATMOSPHERE.

THE local impurities present in our atmosphere differ from those considered in the last chapter, by only existing near the spot where the cause for them is found, and not, as in the former case, generally distributed throughout the air. These local impurities may be divided into solids, liquids, and gases, and it is to the first class that the most important of the impurities belong.

If a beam of sunlight or a ray of the electric light be allowed to pass through the air in a darkened room, its course is made visible by some of the light being reflected by minute particles of suspended matter; and if this air has been previously filtered by passing it through cotton wool no such reflection takes place, and the ray is not apparent until it falls on the opposite wall; these little particles are too minute to be detected by the naked eye, and it is only when they intercept and reflect some of the rays of light that they stand revealed as the "motes in a sunbeam." The nature of the particles composing these solid impurities are of the most varied nature, and when collected are found to be partly mineral and partly organic, consisting of silicious and carbonaceous matters, hair, epidermis from the skin, fragments from

the cellular tissues of plants, pollen from various kinds of grasses, and also sporidiæ of fungi and bacteria.

These constituents when the air is at rest settle down on various exposed surfaces in the form of dust, and in doing so undergo a rough separation, the dust collected from flat horizontal surfaces being far richer in mineral constituents than the lighter form of dust which is to be found in hanging draperies, the rough surface of wall papers, and other vertical surfaces; the heavier dust is found to contain ground-up silicious matter, reduced to an impalpable powder by the traffic in the road; small particles of salt, which have had their origin from the evaporated particles of sea-water borne enormous distances inland by the wind; and of sulphate of soda, and other salts which vary very largely in character with the locality in which the sample is collected. If a sample of dust be collected, and be then carefully ignited, the organic matter and any salts of ammonium which may be present are burnt away, whilst these mineral constituents are left unacted upon; and in this way it has been shown that more than one-half of the suspended matters in the air are of organic origin, whilst a considerable proportion of these again consist of germs which are capable of setting up various forms of fermentation, disease, and decay.

The importance of the work done by the solid constituents of the atmosphere is only now beginning to be recognized, attention having been especially drawn to this by the wonderful researches of Pasteur, which mark one of the most important eras in scientific research; and it is to him that we are indebted for the knowledge that it is to these germs that the formation of various organisms appearing during decay owe their origin, and not to spontaneous generation, which used to be the generally accepted idea.

Pasteur collected the lightest portions of dust, which are those particles left floating in the air after the heavier portions of matter have settled down, by gently drawing air through a plug of soluble collodion cotton; and when sufficient dust had been in this way collected, he dissolved the collodion cotton in a mixture of alcohol and ether, and examined the residual particles under the microscope, and was able to show that there existed in the air a large though variable number of organized spores and germs.

He also found that if he took solutions of sugar and mixed them with the liquid from beer yeast and left it exposed to air, decomposition was rapidly set up; if, however, the mixture was kept in contact only with air which had been previously heated, it would remain for months unchanged; but on putting into it some of the germs collected from the air, decomposition was set up in a few hours, whilst an extension of the experiments to other easily alterable fluids, such as milk and wine, showed that their decomposition was governed in much the same way.

If you take a pot of ordinary paste, and having used what you want of it, leave the remainder on the shelf and forget it for a few days, on again taking it down, you will probably find the surface coated with a fine crop of mould or mildew. Take some of this mould and examine it under a microscope, and you will see something strongly resembling a bed of rushes; keep it another few days, and you will notice that some of these rushes have developed little pods not unlike poppy heads; another week passes, and these pods having ripened split open, and myriads of little germs float away into the air to carry on Nature's cleansing work, for wherever a germ alights on a substance capable of turning mouldy, the same action will be set up which took place in

the paste, and the constituents of the matter, be it what it may, will, by the natural decompositions so started, be resolved into simple gaseous products, which Nature will again utilize for building up fresh organic compounds.

All forms of putrefaction and decay are brought about in organic substances by such means as these, and the preservation of various forms of food entirely depend upon either isolating it from contact with the germ-laden air, or else destroying or rendering dormant the germs themselves.

For the development and action of the germs, moisture and a moderate temperature are necessary, so that if a substance be rapidly dried or kept at a very low temperature, decay is arrested. The drying process for preserving meat is probably the oldest, and many examples of dried provisions have been found in Egyptian tombs; whilst in more modern days, the dried South American beef is a well-known sample of this process.

At the present time the preservation of meat by cold is rapidly becoming one of the most important factors in our food supply, and fleets of steamers fitted with various methods for freezing and keeping meat, fish, and poultry in the frozen state, supply the London market with a far higher percentage of transatlantic produce than is generally supposed.

In the early experiments made in this direction by Harrison and others, ice was used as the refrigerating material; but it was found necessary to have more reliable methods of producing cold, and at the present time the low temperature produced by the absorption of heat during the rapid conversion of readily volatile liquids into gases, or the expansion of compressed air, are the processes most usually employed,

In tinned meats and provisions, decomposition is prevented by destroying the germs present in the tins and preventing the access of air. To do this, the most usual method is to put the meat into the tin and solder it down, leaving, however, a pin-hole in the cover through which air and steam can escape ; the tin is then immersed in a solution of calcic chloride which boils at a considerably higher temperature than pure water, and is heated from ten to twenty degrees above the ordinary boiling point ; this causes the expulsion of a large proportion of the air present and sterilizes any remaining germs, the pin-hole being then closed by a drop of solder, and the tin rendered air-tight. Meat treated in this way has been kept for periods extending over fifty years, and on opening has been found to be as fresh and as eatable as when first sealed up.

Many attempts have been made to preserve provisions by chemical means, such as treating them with saline solutions, glycerine, and boracic acid, all of which exercise a certain amount of influence in retarding decay. Some of these so-called "antiseptics" have succeeded to a certain extent, boracic acid being now very largely used as a preservative for milk, butter, and cream ; but it is a very open question whether the use of these bodies should be encouraged, as but little is known of their action upon the system ; and it is more than probable that the same substances which can prevent the action of the bacteria giving rise to decay, will throw a greater strain upon the digestive organs of the body.

Decay and putrefaction are the great factors of change which Nature utilizes for removing the waste products of animal and vegetable life, and for once more bringing them into a condition in which living things can again assimilate

and use them for building up their tissues and carrying on their functions. Without decay the dead animal matter would remain choking the face of Nature, and life would be impossible, because the food of life would be cut off; and it is the almost imperceptible germs floating in the air which start this marvellous natural action, germs so minute that it requires the strongest microscope to detect them, yet so potent that the whole balance of life hangs on their existence.

Not only does the air carry these wonderful scavengers of natural waste, but also the germs of disease, the so-called infectious diseases being, as a rule, communicated by minute air or water-borne germs, which, coming in contact with a system ripe for sickness, take root and propagate the ailment which gave them birth. A healthy subject may breathe or drink in these germs, and no ill effects may follow, but as sure as they find a place in the system enfeebled by our faulty methods of life, so surely is the disease spread.

This again is a natural arrangement tending to the survival of the fittest and the clearing away of the weak and sickly, who by perpetuating the race tend to deteriorate it.

It has been calculated that a healthy man actively employed in a town like London or Manchester breathes in during ten hours something like $37\frac{1}{2}$ million spores and germs.

It has before been pointed out, that the percentage of oxygen varies but little in good and bad air, and yet the air of one locality is celebrated for its health-giving properties, whilst the air of some other neighbourhood is as notoriously bad; and recent researches point to the fact that these hygienic influences are greatly dependent upon the quantity and character of the organic matter, germs, and

spores which it contains, and which rapidly increase in number in the vicinity of a large town ; and also to the carbon dioxide, which increases in so nearly the same ratio as the organic impurities, that in enclosed spaces, at any rate, the amount of this gas present is taken as a very fair indication of the purity of the air.

The other solid impurities to be found in the air, the particles of sand, or carbon, and of ground-up road-metal, although they are extremely injurious to the system, only act by irritating the eyes and lungs, and so increasing inflammatory diseases of those organs.

The liquid impurities in the atmosphere are very few in number ; indeed, except when sudden cold, under particular circumstances, acting on air charged with water-vapour, causes the formation of a cloud on the surface of the earth, or when the excessive and incomplete combustion of large quantities of bituminous coals gives rise to small quantities of oily vapours, they may be said to be absent. The question of fog and its formation, and effect on health, is so important, that it will be well to consider it at length, and this will be most conveniently done whilst speaking of water and the formation of clouds.

The local gaseous impurities are many, and with the exception of the foul gases emanating from sewage, have more effect upon vegetable than upon animal life. Sewer gas, from the disastrous effect it often produces upon health, and its too frequent presence in our habitations, demands considerable attention. Whenever animal excreta is undergoing those changes which will gradually resolve it back into harmless and necessary constituents of life, gaseous products are freely given off ; and amongst the gases and vapours so evolved are some so offensive and

penetrating in odour that they act as a danger-signal, to warn those whose noses are assailed, that inodorous but often highly dangerous germs and products are present.

In many forms of animal matter small quantities of sulphur are to be found, and during processes of decay this unites itself with hydrogen, and sometimes carbon, to form the gas sulphuretted hydrogen, and even more offensive organic sulphides. A good example of this is to be found in an ordinary egg—the white of the egg, albumen as it is scientifically called, contains sulphur, which in the fresh egg cannot be detected by the nose; but directly decay is set up, the sulphur is evolved in combination with hydrogen as sulphuretted hydrogen gas, the well-known odour of which is only too apparent, whilst even before the nose detects it, the blackening of silver spoons from the formation of sulphide of silver shows the presence of the sulphur.

The tarnishing of silver and of plated goods is entirely due to the presence of traces of this gas in the air of towns, whilst the discolouration and browning of white paint so frequently observed, not only in ordinary house paint, but also in pictures, is also brought about by a like cause. Most of the white pigments at present in use consist of compounds of the metal lead, which, like silver, eagerly combines with sulphuretted hydrogen to form a black sulphide, which when present in even minute quantities destroys the purity of the original colour.

When sulphuretted hydrogen is present in the air in large quantities, it becomes itself poisonous, but minute traces, although extremely offensive to the nose, have little or no effect upon the health; but the same kind of decomposition which liberates the sulphuretted hydrogen also sends adrift into the air many germs and spores capable of setting up

the same kinds of fermentation which gave rise to them, and although in many cases these may be harmless, yet there may be present amongst them the germs of many of the most fatal diseases, and it is for this reason that every precaution should be taken to avoid all risk of leakage of the sewer gas into the air. In our large towns far too little attention is paid to the ventilating outlets from the sewers, and on a cold day they may be seen steaming into the air in our roads, and often making themselves distinctly perceptible to the nose.

It is manifest that there must be free outlets for the sewer gases into the air, or else they would force the water traps which stand between us and their baneful influence in the house, but whilst doing this, it is perfectly easy to prevent the escape into the atmosphere of any noxious gases.

Freshly-burnt wood charcoal has the power of absorbing and condensing many gases in its pores to a remarkable extent, the power varying with the nature of the gas, so that whilst it will absorb about one hundred and seventy times its own volume of ammonia gas, it will only take up about eighteen of oxygen. The gases most readily absorbed, however, are as a rule those most noxious to either nose or health, and the action of the charcoal by no means ends with absorption, as by condensing the gases and organic vapours together with oxygen in its pores, the latter is rendered so active that it attacks and destroys them, carbon being oxidized to carbon dioxide, hydrogen to water-vapour, and sulphur to sulphur dioxide. It has been abundantly demonstrated by the researches of Dr. Stenhouse and others, that this action is so effective, that if trays of freshly-burnt charcoal were fixed below the sewer-traps, in such a way

that the escaping gases and vapours would have to pass through it, no trace of deleterious gaseous matter would escape, and by renewing the charcoal once a month, they could be kept in efficient working order.

During certain manufacturing operations small quantities of hydrochloric acid gas find their way into the atmosphere, with most deleterious results upon the foliage in the immediate neighbourhood, one volume in twenty-five thousand of air being sufficient to rapidly wither and destroy growing plants.

At the present time in England the escape of this gas in large quantities has to a great extent been put a stop to, but in small quantities it is still given off from the potteries during the process of salt-glazing earthenware and stone-ware goods, and from other minor sources.

When the clay, or rather the mixture of clay and substances intended to prevent shrinking or to give adhesion to the mass, has been modelled and baked in the pottery-kiln, it is in the condition known as "biscuit," and is so porous that it would allow liquids to pass through it; and in order to prevent this the surface has to be glazed, which is done by throwing a few handfuls of common salt (sodic chloride) into the kiln furnace; the salt vapourizes, and the vapour acting upon silica on the surface of the pottery forms a very fusible glass-like glaze, whilst at the same time hydrochloric acid gas escapes.

This gas used to be given off in enormous quantities during the manufacture of washing soda, and so serious was the effect upon vegetation in the districts favoured by the alkali works, that they were compelled by law to condense the fumes and prevent the escape of the gas.

This can be readily done, as hydrochloric acid gas is one

of the most soluble gases known, a pint of water being able to absorb about five hundred times its own volume of the gas at ordinary temperatures ; so that by making the flue gases pass up a tower filled with coke, bricks, or other insoluble substances, whilst water trickled slowly down, the escaping vapours were washed free from the acid, and the solution of the acid gas in water, known as hydrochloric acid, spirits of salt, or muriatic acid, was formed.

This being produced in very large quantities, was at first a serious trouble to the alkali maker, as he had no market for it, and did not know how to get rid of it ; if he ran it into the streams, it killed the fish and brought the conservators upon him, whilst if it was run into holes in the ground, the quantities accumulated so as to become unmanageable. It was soon found, however, that it could be utilized on a large scale for the production of chlorine, used in making bleaching powder, and the despised bye-product soon became an important ally in the bleaching and calico-printing industries.

So great is the affinity of hydrochloric acid gas for water, that if a cylinder of the clear colourless gas be opened in the air, it forms dense white fumes by combining with and condensing the aqueous vapour held invisibly suspended in the air, and it is this intense affinity for moisture which causes it to kill vegetation by extracting moisture from the leaves.

In France the heavy import duty results in the survival of those abominations, the old sulphur matches, which, being manufactured in the country, still disgrace Paris and the other French centres of civilization. Scratch one of these, and the burning of the phosphorus mixture ignites the sulphur, which, burning with a pale blue flame, in turn

ignites the wooden splint, and whilst doing so emits that strong choking odour which is popularly supposed to be characteristic of Satanic attributes.

This gas is sulphur dioxide, and is always produced when sulphur or compounds containing sulphur burn in air or oxygen. In all big cities consuming coal as the principal form of fuel, traces of this gas will be found in the air, as all coal contains certain quantities of a sulphide of iron and copper, called "pyrites," which forms the golden laminæ so often seen in the cleavage of a piece of coal, and which during combustion gives rise to sulphur dioxide. This gas has nearly as deleterious an effect upon plant life as the hydrochloric acid gas, but unless present in sufficient quantity to irritate the respiratory organs, has little or no effect upon health; indeed, being an admirable disinfectant, small traces tend rather to purify the atmosphere from noxious germs than to render it unhealthy.

This practically completes the list of important local impurities; and with those of Nature's production we see the same marvellous adaptation to a definite end which is so marked wherever we can follow natural processes. What can be more beautiful than the wonderful action of the germs in reforming waste matter into the food of life, whilst even the noisome sulphuretted hydrogen has its natural use as the herald of danger?

CHAPTER V.

THE CAUSES WHICH TEND TO KEEP THE COMPOSITION OF THE ATMOSPHERE CONSTANT.

In the early half of this century the great chemist Faraday calculated the total amount of oxygen present in the atmosphere, and found that there was present no less than 1,178,158,000,000,000 tons; but enormous as this quantity is, the amount which is daily used up by processes of animal life, combustion, and decay would rapidly cause a deterioration in the atmosphere.

It was Faraday also who first calculated approximately the amount of the life-supporting constituent of the air which is in this way daily used up, and his results are tabulated as follows :—

		lbs.
Respiration of whole population	...	1,000,000,000
Respiration of animals	... ..	2,000,000,000
Combustion and fermentation	...	1,000,000,000
Decay and other processes	...	4,000,000,000
		<u>8,000,000,000 lbs.</u>

8,000,000,000 lbs. = 3,571,428 tons in a day, or
1,304,642,357 tons in a year,
a rate of consumption which would use up the total oxygen

present in about 900,000 years ; but it must be remembered that even the withdrawal of one per cent. of the oxygen present would exercise a serious effect upon the health of men and animals, and that moreover the withdrawal of the oxygen is due to its conversion into carbon dioxide, which would itself rapidly render the air unfit to breathe.

It is manifest from this that Nature must have at hand methods not only for the removal of carbon dioxide from the air, but also for the production of oxygen, as otherwise the composition of the atmosphere instead of being so constant as to defy the detection of any considerable variation, would rapidly deteriorate and become unfit to support life.

The main factor in this marvellous natural work is to be found in the plant world, as it is the growth of vegetation which performs the wonderful work of undoing the vitiation of the atmosphere by animal life, and once more liberating oxygen from the carbon dioxide.

The surface of every form of vegetation contains innumerable small openings, called stomata, which end in little cells filled with a green colouring matter, called chlorophyll, the presence of which gives the distinctive colour to the plant. But little is known of the composition of this remarkable substance, which may be extracted by macerating grass or green leaves with spirits of wine, when the green colouring matter from the ruptured cells dissolves in the spirit, and yields a green solution which may afterwards be concentrated by evaporation. This chlorophyll appears to consist of two compounds, one of them a yellow substance, the other a blue, and it is generally supposed that the autumn tints are to a great extent due to a gradual disappearance of the blue colouring matter, which causes a change in colour, from green to yellow and yellowish-brown. During

the growth of a plant many changes take place. As soon as the seed is germinated it begins to absorb from the soil and the air, water and oxygen, and when a certain stage is reached the formation of chlorophyll commences, and from that moment the growth of the plant is as dependent upon the air as upon the soil for its nourishment; for under the exciting influence of sunlight the chlorophyll absorbs carbon dioxide, and breaks it up, retaining the carbon, which is one of the chief constituents of woody fibre, whilst oxygen is returned to the atmosphere, and renders it fit to support life. The fibre of a plant, which forms the whole of the solid portions, consists of a compound of carbon, hydrogen, and oxygen, called cellulose, and the carbon of this is to a very great extent derived from carbon dioxide, whilst the oxygen and hydrogen are obtained from water, which is also an essential to the growth of the plant.

In Nature's wonderful laboratory these three simple elements are built up into the basis of every form of vegetation, so that in our atmosphere combustion and animal life cause a continual withdrawal of oxygen with production of carbon dioxide, whilst plant life once more restores the balance of Nature. What more wonderful cycle of changes can be imagined? When we burn a log of wood the result of combustion is carbon dioxide and water-vapour, and no sooner is the destructive change completed, than at once Nature steps in, and aided by the sun commences again to reconstruct the woody fibre. This change only taking place under the influence of sunlight, it is manifest it cannot proceed at night, and it has indeed been found that a slight retrograde action goes on in the dark, plants slowly absorbing small traces of oxygen, and giving out an equal amount of carbon dioxide; this action is very slight, but still dis-

tinctly perceptible, and it is therefore better not to have too many plants in a room at night, whilst no better or healthier companions can be found in the daytime ; it is a recognition of this fact which has given rise to the prejudice against flowers in the sleeping-rooms.

Green leaves and sunshine being the primary essentials in this wonderful change, it will at once occur to many minds to wonder how in a city like London the change can go on, as not only is vegetation scanty, and only existing for a limited period, but even where vegetation is present sunshine is often more noticeable from its absence than its presence ; moreover it has been pointed out that the constituents of the atmosphere have each their own particular weight, and that the carbon dioxide is far heavier than the oxygen, whilst the oxygen in turn is heavier than the nitrogen, the ammonia and water-vapour forming the lightest of all the constituents ; so that if the same laws held good for gases as regulate liquids, we should expect them to form themselves into layers, with the heavy carbon dioxide next to the earth, forming a layer which would at once put an end to life ; these objections are however provided for by another great natural law, known as "the law of diffusion of gases," which causes all gaseous bodies to intermingle, no matter how different may be their respective weights.

If we take some mercury in a glass vessel, and pour upon the top of it some water, no matter how long we leave them, the mercury, being 13·6 times as heavy as the water, will remain at the bottom, and no tendency to intermingle will be manifested ; if however we take some oxygen in a cylinder, and place a second cylinder, containing hydrogen, mouth to mouth with it, we shall find that in a very short

space of time both cylinders will contain an equal mixture of the two gases. This phenomenon was first proved to take place by Priestley, but it was Dalton in 1803 who first conclusively showed that a lighter gas cannot rest upon a heavier one, but that the two gases diffuse themselves through each other until a condition of equilibrium is reached ; but the final step in the discovery of the important law of diffusion of gases was made in 1832 by Thomas Graham, who showed that although all gases intermingled, yet that their weight played an important part in the rate at which this took place, and after many experiments he showed that this could be enunciated as a law, and that "the relative rates of diffusion are inversely proportional to the square root of the densities of the gases."

The density of a gas is the ratio of its weight as compared with an equal volume of hydrogen, measured under similar conditions of temperature and pressure ; so that if we took a pint of oxygen gas, and found that it weighed sixteen times as much as a pint of hydrogen, measured whilst the barometer and thermometer remained constant, we should say that the density of oxygen was 16. The square root of 16 is 4, and hydrogen being taken as the unit of weight amongst gases, is said to have a density of 1, and the square root of 1 being 1, if we take a vessel of hydrogen and a vessel of oxygen, separated by a porous diaphragm, or a card in which a small hole had been pricked, it follows from Graham's law, that four volumes of the hydrogen will pass through the hole in the diaphragm into the oxygen, whilst only one volume of oxygen will in the same period of time find its way back into the cylinder originally containing hydrogen, and this will go on until the pressure in what was the oxygen vessel will get so high that it stops the action.

If a long glass tube (B, Fig. 12) be taken, and one end be closed by casting into it a plaster of Paris plug (c), plaster of Paris being full of small pores when dry, and if the tube above the plug be now closed with the thumb, or an india-rubber cork (D), and the tube filled with hydrogen by upward displacement, it will be found that on plunging the

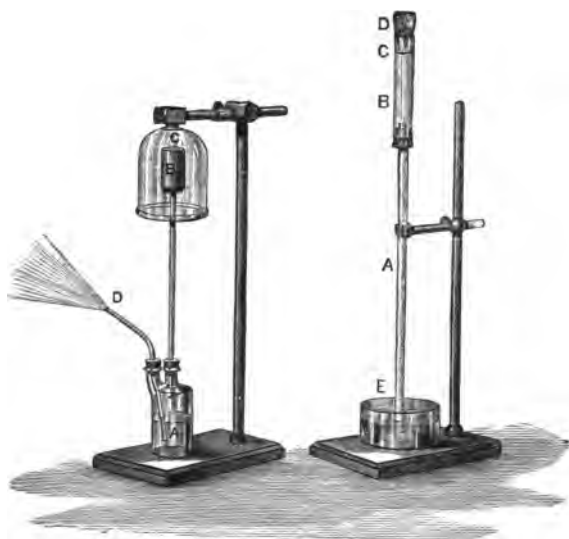


Fig. 11.

Fig. 12.

open end of the tube under water, and removing the thumb or cork from above the plaster plug, the water will rise several inches in the tube against the force of gravity. Air is volume for volume 14.47 times heavier than hydrogen, and therefore the hydrogen which is inside the tube will pass out through the porous plug about $3\frac{3}{4}$

times more quickly than the air can pass back, and this reducing the pressure in the interior of the tube, sucks up the water. It might be objected to this experiment that hydrogen, being so much lighter than air, would have a natural tendency to rise, and in doing so would draw up the water after it, and this objection, which is absolutely fallacious, can be proved to have nothing to do with the phenomenon by making the experiment under the reverse conditions (Fig. 11). A small porous vessel of unglazed earthenware (B) is fixed to the end of a glass tube, which is fitted gas-tight into a glass bottle full of water, whilst a second tube open to the air (D) also passes into the same vessel, and descends well below the surface of the water; if now a jar of hydrogen (C) gas be placed over the porous earthenware pot, so as to envelope it in an atmosphere of hydrogen, the hydrogen will pass in through the porous vessel so much more quickly than the air can escape out, that an increase of pressure will be created on the surface of the liquid in the bottle, and this will drive the water out through the open glass tube in a jet.

It is this wonderful power of diffusion possessed by all gases which is the chief factor in keeping the composition of our atmosphere constant, as aided by air currents and wind it keeps the whole of the gases present in the atmosphere thoroughly intermixed, and the carbon dioxide formed in our great cities by combustion and respiration is rapidly removed from the places where it is generated, and is carried to more favoured climes, where the presence of ample vegetation and the influence of the sun's rays once more liberate from it the life-supporting oxygen, which in turn is borne back to the cities where it is required.

It is in this way that Nature deals with what would be,

if it were allowed to accumulate, the chief impurity in the atmosphere, with the result that in the open air carbon dioxide rarely reaches a proportion of more than 0·04 per cent., an amount innocuous to human life, and we have now to consider how the other impurities are prevented from reaching a deleterious proportion, except in fortunately rare instances. It has already been pointed out that water-vapour rarely rises above a healthy limit, as directly the air is saturated the surplus is deposited as dew, fog, or rain, a subject which will be discussed more fully in a later chapter, and we have therefore only now to consider causes tending to remove such purely local impurities as sulphurous acid, hydrochloric acid, and sulphuretted hydrogen, together with the solid impurities, such as dust, consisting of particles of carbon and carbonaceous matter from the incomplete combustion of coal, germs of various kinds, and the débris resulting from the attrition of various forms of animal and mineral matter, and also sometimes ammonia salts, formed from the decomposition of nitrogenized organic matter. Such impurities as these are nearly always to be found in the air of large towns, more especially when the products of ordinary life are augmented by those formed in various manufacturing processes, and the chief method by which these are got rid of are wind, rain, and to a small extent the oxidizing influence of oxygen and its more active allotrope ozone.

Wind acts merely by scattering and diffusing the impurities, so that those which would be extremely noxious if confined to a limited area, by being spread over a much larger space are rendered comparatively innocuous. A case of this kind may be found in the sulphurous acid present in the air of all big cities, and which arises almost entirely

from the combustion of coal, which contains nearly always from one to two per cent. of sulphur. During windy weather hardly any is to be perceived, whilst with still air, and during the prevalence of fog, the amount present increases with enormous rapidity, and it is indeed the presence of this gas in town fogs which is the principal cause of their being so much more injurious than an ordinary white country mist.

Rain acts in the first place by washing the solid impurities out from the air, and in the next place by dissolving gaseous impurities—sulphurous acid, hydrochloric acid, sulphuretted hydrogen, and ammonia all being readily soluble, with the result that town air is always perceptibly purer and fresher after heavy rain than in dry weather. The proof of the cleansing action of rain is to be found in the condition of rain water collected in various localities ; where the rain has fallen through clean country air, and has been collected from clean country roofs, no purer or better sample of natural water could be obtained, but where it has performed the function of cleansing the air over one of our great cities, and has then washed down the dust-coated roof of a town house, it would be hard to find a fouler sample of the liquid, as will be at once realized by thinking of the filthy and often unpleasantly odorous fluid which occupies the town water-butt. Snow is even more efficacious than rain in doing this, and where the snow has fallen on the glass roof of a greenhouse, it will be noticed that when it melts it leaves behind a black deposit, consisting of the solid matter which it has collected in its passage through the air. A recent analysis of a deposit of this character formed on the glass roofs of Messrs. Veitch's orchid houses at Chelsea gives a very good idea of the constituents of these solid impurities—

Carbon	...	...	...	...	39'00 per cent.
Hydrocarbons	...	...	...	...	12'30 " "
Organic bases	...	...	...	...	1'20 " "
Sulphuric acid	...	...	...	...	4'33 " "
Hydrochloric acid	...	...	...	...	1'43 " "
Ammonia	...	...	...	...	1'37 " "
Metallic iron and magnetic oxide	...	...	...	...	2'63 " "
Other mineral matter, chiefly silica and ferric-oxide	...	...	...	...	31'24 " "
Water not determined.					

In cases where long drought prevents the rapid clearance of the air by this means, the heavier of the solid particles settle by gravity, whilst the particles of carbon and carbonaceous organic matter are slowly oxidized by the oxygen and ozone into carbon dioxide, in which form the vegetation removes them from the air.

CHAPTER VI.

THE AIR OF ENCLOSED SPACES AND VENTILATION.

IN the open air the provisions of Nature, enumerated in the last chapter, amply suffice to maintain the air in a fit condition for supporting animal life ; but when we are in an enclosed space, such as a room, the artificial barriers which we put to these natural processes so interfere with the work of purification, that unless we adopt artificial means to aid Nature we rapidly contaminate the air to a point at which it becomes unfit for respiration.

Air commonly contains on an average 4 parts of carbon dioxide in 10,000, and it is found that if the air of a room exceeds this amount by 2 parts per 10,000, the air is no longer fresh, and has a stuffy smell, owing partly to the presence of organic matter and moisture ; therefore, 6 parts per 10,000 are fixed as the utmost limit of impurity allowable for healthy rooms.

In order to fully understand this we must consider what takes place during respiration. The blood is distributed to the body by a complete set of pipes ; one set carries blood from the heart, and are called arteries, whilst another set carries blood to the heart, and these are called veins ; between the extremities of the arteries and the commencement

of the veins, we find a minute system of vessels, called the "capillaries," which connect the arteries and the veins. The heart is divided into four chambers, and the blood is brought to the heart by two great veins, one from the lower and the other from the upper extremities ; these empty themselves into the right-hand upper chamber ; from this it passes into the right-hand lower chamber, whence it passes through a vessel which terminates in the capillaries of the lungs. These capillaries communicate with four large veins which bring the blood back to the left-hand upper chamber of the heart, whence it passes into the left-hand lower chamber and is forced out into the great artery, which distributes it to the different organs and tissues of the body. In the lungs the blood comes in contact with the inspired air, admitted to the air-cells of the lungs by the windpipe, and here a great change takes place in the character of the blood ; the blood as it comes into the lungs is purple, and is charged with carbon dioxide, but in the air-cells of the lungs this gas passes out from the blood and oxygen passes in by diffusion, and takes its place, whilst the colour of the blood turns from purple to red, and passes back through the heart to the artery and the system ; here in the capillaries the tissues of the body take the oxygen from the blood, replacing it by carbon dioxide, with the result that it again changes to purple, and in this condition returns by the veins to the heart and lungs, once more to give up carbon dioxide and take in a fresh supply of oxygen. The purple blood is called "venous" or the blood of the veins ; the bright scarlet blood is called "arterial."

Whenever we move some of the tissues of the body are used up, and this waste matter unless removed would accumulate and cause death. The tissues consist chiefly of

carbon, nitrogen, and hydrogen ; and when the oxygenated blood meets these it attacks and burns them, converting the hydrogen into water, which escapes as perspiration, exhaled moisture, and urine, whilst the carbon dioxide is brought back to the lungs and discharged with the expired air, and it is this process of slow combustion which maintains the heat of our bodies.

When the quantity of carbon dioxide present in the air of a room increases much beyond 6 parts in 10,000, it commences to interfere slightly with the diffusion of oxygen into the blood through the air-cells, and also begins to check the throwing-off of the carbon dioxide from the venous blood, and in this way affects the health.

An adult exhales 6 cubic feet of carbon dioxide in ten hours ; it is therefore evident, in order that the room in which he is living may be kept fit for respiration, that he must be supplied with 30,000 cubic feet in ten hours, or 3,000 in one hour.

A person occupying a room for seven hours would require 21,000 cubic feet of air, and if no means were provided to change the air, it would have to be 70 feet long, by 30 feet wide, by 10 feet high. It is manifest that it would be quite out of the question to have rooms of this size, and so the process of ventilation is made use of in order to change the air.

A space of from 1000 to 750 cubic feet of air should be allowed for each person, as it is found impossible to change the air in a room more than three or four times in an hour without creating draughts.

The following points are to be observed in the provision of ventilation : (1) The air which enters should be pure. (2) Its movement should be so slow as to be imper-

ceptible, otherwise it gives rise to draughts and sensation of chill. (3) The air introduced should be distributed evenly throughout the room, in order to change every portion. (4) The air should be removed as speedily as is consistent with comfort, in order to insure against the risk of the same air being breathed more than once.

The means employed to set air in motion for processes of ventilation may be of two kinds, natural or artificial: the natural means are diffusion, wind, and the differences in weight between unequally heated masses of air. Air diffuses with rapidity through cracks and openings due to bad carpentry and careless building, and also through porous material, such as bricks and mortar, &c.

We have seen that the diffusion of gases takes place at a rate which is inversely proportional to the square root of their densities, and that therefore two gases of widely different weights intermingle with great rapidity, whilst if two volumes of gas have much the same density, they show but little tendency to mix; from this one would expect that the air inside a room, being of nearly the same composition as the air outside, would have no tendency to set up diffusion currents, nor does it if the temperature existing in the room and in the open air is the same, but it must be borne in mind that the causes which tend to contaminate the air in an enclosed space also, as a rule, tend to increase its temperature.

All gases expand with great rapidity with rise of temperature, and it can be experimentally shown that they all do so at the same rate, a fact which is enunciated in the law that all gases expand $\frac{1}{273}$ of the volume which they occupy at 0° Centigrade, for each degree Centigrade rise in temperature; so that if a gas be heated from 0° C. to 273° C. it doubles its

volume, and it is manifest therefore that a pint of air at 0°C . will weigh just twice as much as a pint of air at 273°C ., or in other words, the warmer the air the lighter; and it is this alteration in weight, due to increase in temperature, that causes diffusion to take place between masses having really the same composition; even such a small difference in temperature between the external and internal air as 2.5°C . sets up the action, and with this difference in temperature a plain wall, according to the material of which it is built, allows the passage of air through each square yard of it at the following rates per hour—

				Per hour.
Sandstone	...	...	...	4.7 cubic feet.
Quarried limestone	...	...	...	6.5 " "
Brick	...	...	...	7.9 " "
Loose sandstone	...	...	...	10.1 " "
Mud	...	...	...	15.4 " "

and it has been experimentally shown that with an ordinary brick and mortar wall, a room containing 2,650 cubic feet of air has its entire contents changed once in an hour, when the temperature inside is 18°C ., and the temperature outside 0°C .; the amount of change, owing to diffusion, rapidly diminishes as the external temperature increases, and for this reason a room is often better ventilated in winter with all the windows shut and with a roaring fire in the grate, the air outside being below the freezing-point, than in summer with the windows wide open, and the external and internal temperatures very nearly the same.

Although diffusion plays a great part in aiding ventilation, still it is totally insufficient for keeping the air of living-rooms in proper condition, and other methods of ventilation have therefore to be used in order to aid it. Our ideas on

the subject of ventilation are commonly limited to throwing open the windows, which, although it to a certain extent supplies fresh air, still as a rule does so in a very undesirable manner, as the inrush of cool air is in many cases sufficient to produce draught, the avoidance of which is one of the great aims of good ventilation. If air is moving at the rate of a mile an hour, which is equal to about eighteen inches per second, its motion is imperceptible to our senses, and no chilling sensation to the body is perceived, and it is at about this rate of flow that in good ventilation air should be supplied in a climate like ours, anything much beyond this rate producing draught.

The human body is capable of withstanding great changes of temperature without the health being affected, as long as those changes affect the body fairly evenly; but if you have a local cooling of one part or side of the body, the natural balance seems to be upset, and you have chills and serious disturbance to health resulting, and it is for this reason that draughts are so injurious, as a rapid current of air unduly cools the side on which it impinges, and produces chill.

It is evident that in order to ventilate a room air must be set in motion, and the chief factor in doing this is heat. When we breathe the breath leaves the body at a considerably higher temperature than the surrounding air, and the carbon dioxide laden products of respiration at the temperature at which they are exhaled being lighter than the surrounding air rise towards the ceiling, so that for a considerable time the strata of air in which we are breathing is but little affected; the body however continues to heat the air, and gradually a rise in temperature takes place throughout the whole mass, and if no means have been taken for changing the air as it rises to the top of the room,

as it cools it will again descend, and the deterioration of the atmosphere rapidly becomes apparent. When, as well as human beings, the room also contains candles or other illuminants burning, the rise of the vitiated atmosphere to the top of the room becomes still more noticeable, and the result is that in most methods of ventilation arrangements at the top of rooms intended to remove the impure air before it has time to cool and descend have been adopted ; but a phase of the question, which has been too often overlooked, is that it is absolutely useless to supply an opening near the roof of the room for the exit of the hot vitiated air, unless you also supply means for the entrance of fresh cool air.

If we take a large bell jar with a wide opening at the top, and stand it over a candle, taking care that the bottom is air-tight, the candle will in a very short time go out, because the hot products of combustion as they stream up and attempt to leave the jar through the opening in the top will meet a current of fresh air trying to find its way in, with a result that the meeting currents block each other, and the candle is extinguished almost as rapidly as if the top of the jar had been closed with a cork. If however the jar be stood upon a match, so as to form a crack through which air can enter at the bottom, the uprush of the heated products of combustion will draw in cool fresh air at the bottom of the jar, and a free current being set up, the candle will continue to burn until it is all consumed.

In all methods of ventilation therefore, there should be free exit in the upper part of the room for vitiated air, and a free entrance in the lower part of the room for fresh pure air, this entrance being so arranged that there shall be no fear of its creating draughts ; and the arrangement by which this can be done has to a great extent to be modified, according

to the methods employed for heating and lighting a room, which play an important part in deteriorating the air by removing oxygen and returning it as carbon dioxide; but owing to the tendency to upward movement produced in the foul air by rise in temperature and moisture formed during combustion, they may also be made important factors in ventilation.

The most usual method adopted in England for warming rooms is the open fireplace—at once the most comfortable and most wasteful that could be adopted. If a pound of coal be thoroughly and completely burnt, and all its heat of combustion utilized in heating, it would be more than sufficient to raise the temperature of a room 20 feet square and 12 feet high, ten degrees above the temperature of the outside air, and if there were no ventilation, and the walls were non-conductors of heat, the amount of fuel required to maintain this temperature would be very small; but in an ordinary grate the average consumption is eight pounds per hour; but this consumption of fuel enables the fire to perform other functions besides those of heating, and it may rightly be said to be the great engine of ventilation.

In order to completely burn one pound of coal, 160 cubic feet of air are required, therefore the eight pounds would require 1,280 cubic feet; but at a very low computation the air passes up the ordinary chimney-flue at a rate of from 4 to 6 feet per second, or 14,000 to 20,000 cubic feet per hour, whilst with a velocity of 10 to 15 feet per second, which is often attained, the flow of air would be 35,000 to 40,000 cubic feet per hour; and all this volume of air is warmed and carries away heat with it, whilst the fresh cool air which takes its place tends to lower

the temperature of the room. Another disadvantage is that this large volume of air drawn out by the chimney has to be replaced, and the air entering at a high velocity through the cracks and crevices gives rise to draughts.

When an open fire burns, the radiant heat from it does not directly heat the air, but the fire heats the back, bars, and sides of the grate, and these in turn radiate heat to the walls and ceiling of the room, which again part with their heat to the air in contact with them. From this it is evident that in order to obtain an efficient fireplace, the grate should be made of a bad conductor of heat, but a good radiator—for instance, bricks or tiles should be used rather than iron for this purpose.

The normal temperature of the body is 98° F. or 36·8° C., and this temperature is maintained by the slow processes of combustion going on in the body. By the laws of radiation a heated substance parts with its heat more or less rapidly, according to the temperature of the surrounding bodies, so that if a person be sitting in a room filled with warm air, but near a wall colder than the air, his body will rapidly part with heat by radiation to the wall, and a sensation of chill is the result; but with the open fire this is never the case, as the radiant heat from the fire heats the walls of the room to a temperature higher than that of the air; but when a room is heated by means of hot-water pipes or warmed air, the walls not being heated in the same proportion, although the air may feel warm the walls will remain cold, so that the heat of the body would pass by radiation to the walls and give rise to a sensation of chill.

It is much more healthy to breathe cool than hot air, as bulk for bulk it contains more oxygen.

If the ordinary method of heating by the open fire be

done away with, it has to be replaced either by closed slow combustion stoves, by heating by warmed air, by hot water, by steam, or by gas.

In slow combustion stoves a great saving of fuel is effected, as a much larger amount of heat is obtained per pound of fuel consumed, but they have many drawbacks, as, for instance, in allowing carbon monoxide and various other injurious products of incomplete combustion to escape into the air, and it is therefore imperative that heating by this method should only be employed in lobbies or galleries, where there is ample ventilation provided.

In heating by air, cold air is raised to certain temperatures by passing over heated surfaces, and can then be discharged into the building to be warmed, the great drawback to the system being that the air is in most cases warmer than the walls, and also that it does not permit of any one room being made hotter or cooler than the rest. In warming by hot-water pipes, the water heated in a central boiler is caused to circulate through iron tubes in the chambers to be heated; this system is, of course, open to exactly the same objections as in the case of heating by warmed air. Heating by steam is the method most generally employed in the United States, but in England there is a great prejudice against its use as a heating agent, as for some reason it is not considered safe. In this process the steam is conveyed from the basement by means of pipes to the room, passage, or lobby which is required to be warmed, and there is passed into a coil of pipes called the radiator, which gives an increased heating surface; here the steam is once more converted into water, at the same time giving up some of its heat, the condensation of the steam causing a partial vacuum in the tubes, and so sucks up fresh steam to

supply its place ; the water so condensed then flows back into the boiler, or supply tank, and in turn is again converted into steam. The main drawback in steam as a heating agent is the difficulty which is found in regulating the temperature of the pipes, as the temperature is found to rise very rapidly when the steam is turned on, and falls as quickly when the steam is shut off. Lately gas has come into considerable prominence as a heating and ventilating agent, and is either applied to open fireplaces, where the gas is burnt in large atmospheric burners and is made to heat asbestos, which in turn radiates its heat to the room, or it is used to heat fresh air or a small service of hot-water pipes.

It must, however, be clearly understood that where gas-stoves are used, the same attention must be given to carrying off the products of combustion, as is done with a coal or coke fire, as although smoke is not given off, yet the gaseous products of the combustion are every bit as injurious to health as when solid fuel is employed.

The subject of lighting is so closely related to that of heating and ventilating, that it is important it should be considered in connection with them.

The sources of artificial light are : candles, lamps burning oils, coal gas, arc and incandescent electric lamps. If the sources of light be taken in their historic order, we first come to candles, then to oil, and finally to gas.

If we examine the composition of the light-giving waxes, fats, oils, and gases, it is found that they depend upon the elements carbon and hydrogen for their lighting and heating powers, which by the processes of decomposition and combustion emit light ; the products of the complete combustion of these elements being carbon dioxide and water-

vapour, accompanied by minute traces of other gas, either derived from impurities in the illuminants or from incomplete combustion.

The unit adopted in England for the measurement of the illuminating power of various illuminants in use, is a sperm candle of the size known as "sixes," which when burning under ordinary conditions, consumes 120 grains of sperm per hour, and gives a light known as "one candle-power," and as it is convenient to quote the volume of carbon dioxide and water-vapour derived from the various illuminants per candle-power, it will be valuable, for purposes of comparison, to regard the sperm candle as the type in general use. The constituents of these candles prove on analysis to have the following composition—

Carbon	...	...	...	80.0	per cent.
Hydrogen	...	...	...	13.3	" "
Oxygen	...	...	...	6.6	" "

On complete combustion in air, 120 grains yield 0.41 of a cubic foot of carbon dioxide, and the same volume of water-vapour; or to express these results in other words, these volumes of carbon dioxide and water-vapour are evolved in an hour for every candle-power of illumination obtained by the use of sperm candles.

Various kinds of oil have been employed for illuminating purposes, but petroleum, paraffin or mineral oil is the only one which, owing to its cheapness and high illuminating value, has as yet threatened the popularity of gas. Of late years paraffin has been obtained in such vast quantities that it bids fair to become of paramount importance among the heating and illuminating agents of the future. On analysis ordinary paraffin gives the following composition—

Carbon	...	...	...	86 per cent.
Hydrogen	...	...	...	$\frac{14}{100}$ „ „

The average consumption per candle-power is 62 grains per hour, when burnt in the most improved forms of lamps; the volumes of carbon dioxide and water-vapour evolved on the combustion of this amount of oil are respectively 0·28 and 0·22 of a cubic foot.

Coal gas is obtained by the destructive distillation of coal out of contact with air, and consists of a mixture of several gases, which vary to a considerable extent with the class of coal employed for its production, and also to a considerable degree with the methods employed in its purification.

Since the first introduction of coal gas for illuminating purposes, steady progress has been made in its manufacture and purification, and at the present time there is little to be desired, either in the purity or quality of the gas as supplied to the London consumers. The gas as supplied to London on analysis shows the following composition—

Hydrogen	...	...	...	...	57'10
Marsh gas series	...	...	...	...	33'99
Olefines	...	...	...	...	4'38
Carbon monoxide	...	...	...	...	2'63
Carbon dioxide	...	...	...	...	0'79
Nitrogen	...	...	...	...	0'15
Oxygen	...	...	...	...	0'96
					<u>100'00</u>

Every cubic foot of this gas on combustion yields approximately 0·52 of a cubic foot of carbon dioxide, and 1·34 cubic feet of water-vapour; whilst of course the illuminating

power per cubic foot depends upon the burner in which the gas is consumed.

Selecting burners for photometric comparison and experiment, the following results are obtained—

Type of Burner.	Products of Combustion per candle-power.			
	Illuminating power per cubic ft. of gas consumed.	Carbon d'oxide.		Water vapour.
		Cub. ft.	Cub. ft.	
Batwing ...	2'9	0'18	...	0'46
Argand ...	3'3	0'16	...	0'40
Regenerative ...	10'0	0'05	...	0'13

The figures are obtained by testing the burners with gas of the composition supplied by the London Gas Companies.

Taking the amount of the products of combustion given off per candle of illuminating power, it is easy to arrive at the relative vitiating effect which the various sources of illumination produce on the air of a dwelling-room, and to compare these results with the effect produced by respiration. As has already been stated, an adult exhales 0'6 of a cubic foot of carbon dioxide per hour ; and also that, as the percentage of organic matter in the air of a room increases with rise in percentage of carbon dioxide, the amount of carbon dioxide present may be taken as a very fair indication of the sanitary condition of the air, and, as we have seen, an adult exhaling 0'6 cubic foot of carbon dioxide per hour will need 3,000 cubic feet of air space for healthy respiration. But inasmuch as diffusion through walls, crevices and window-frames, and ventilation by the chimney, changes the air of a room at least three times an hour, 1,000 cubic feet of air space is the quantity decided upon as the allowance per adult in rooms which are to be continuously used as dwelling apartments. Taking now a

small-sized room, say 12 feet by 16 feet by 10 feet, it would not be considered sufficiently well illuminated unless the light were at least equal to thirty-two candle-power. In the following table is given the amount of oxygen used up, and products of combustion formed, by each class of illuminant and burner, in order to secure this result; and the amount of carbon dioxide so formed is also expressed in the number of adults who would exhale the same amount during respiration—

Amount of oxygen removed from the air, and carbon dioxide and water-vapour generated to give an illumination equal to thirty-two candle-power.

Illuminant.	Quantity burnt.	Oxygen removed.	Products of Combustion.		
			Water vapour.	Carbon dioxide.	Equal to adults.
	Grains.	Cub. ft.	Cub. ft.	Cub. ft.	
Sperm candles ...	3,480	19'27	13'12	13'12	21'8
Paraffin oil ...	1,984	12'48	7'04	8'96	14'9
Gas (London)	Cub. ft.				
Batwing ...	11'0	13'06	14'72	5'76	9'6
Argand ...	9'7	11'52	12'80	5'12	8'5
Regenerative ...	3'2	3'68	4'16	1'60	2'6

From these data it would appear that, according to the rules laid down in sanitary science, by which the degree of vitiation of the air of any confined space is measured by the amount of oxygen used up and carbon dioxide generated, candles are most injurious to health and comfort, oil-lamps less so, and gas least—an assumption which practical experience does not bear out; the discomfort and oppression felt by the use of candles and oil being far less than in the use of any of the older forms of gas-burners. The explanation of this is to be found in the following facts: Firstly, in illuminating a room with candles or oil, we are satisfied with less intense and more local light than when we are using gas; and in a room of the size quoted, we should be far more likely to be contented with the use of two candles,

placed near our book or plate, than thirty-two scattered about the room. Secondly, the amount of water-vapour given off during the combustion of gas is greater than in the case of the other illuminants, and the water-vapour causes oppression by absorbing radiant heat from the burning gas, and becoming heated diffuses itself throughout the room.

Dry air is able to take up far more water-vapour than air already charged with it; for this reason the air being laden with water-vapour is unable to take up the moisture given off from the surface of the skin as perspiration with sufficient rapidity, and in this way the functions of the body are retarded, and the slight check so given results in a feeling of oppression. Further, in burning coal gas, if the gas be pure and the gas thoroughly burned, the products may be looked upon as carbon dioxide and water-vapour, but even the purest specimens of gas contain traces of sulphur compounds—the carefully purified gas supplied to London containing ten to thirteen grains of sulphur per 100 cubic feet, in the form of bisulphide of carbon vapour.

When these sulphur compounds are burned, sulphurous acid is the result, which, if it were present in any considerable quantity, would not only be injurious to health, but would also be destructive to bookbindings, furniture, etc., because the sulphurous acid is gradually converted by the action of the atmospheric oxygen and moisture into sulphuric acid. But when we consider the small amount of sulphur compounds in the London gas, and the large volumes of air with which the product of its combustion would be mixed, and when again we consider how small a proportion of this would be oxidized to sulphuric acid in the room, it is unreasonable to hold the sulphur compounds responsible for all the mischief laid to its charge.

A much more serious evil, however, does exist in the products resulting from the incomplete combustion of coal gas, viz. carbon monoxide and acetylene, which are most injurious even in minute traces.

Ever since the structure of flame has been noted and discussed, it has been accepted as a fact beyond dispute that the outer almost invisible zone which is interposed between the air and the luminous zone of the flame is the area of complete combustion, and that here the unburnt remnants of the flame gases meeting the air freely take up oxygen and are converted into the comparatively harmless products of combustion, carbon dioxide and water-vapour, which only need partial removal by any haphazard process of ventilation to keep the air of the room fit to support animal life.

The outer zone of a luminous flame is not the zone of complete combustion ; it is a zone in which luminosity is destroyed in exactly the same way that it is destroyed in the Bunsen burner ; that is, the air penetrating the flame so dilutes and cools down the outer layer of incandescent gas that it is rendered non-luminous, while some of the gas sinks below the point at which it is capable of burning, with the result that considerable quantities of the products of incomplete combustion, carbon monoxide and acetylene, escape into the air, and render it actively injurious.

The gases leaving the luminous flame show that the diluting action of the nitrogen is so great, that considerable quantities even of the highly inflammable and rapidly burning hydrogen escape combustion, while the products of incomplete combustion are present in sufficient quantity to account perfectly for the deleterious effects of gas-burners in ill-ventilated rooms.

GASES ESCAPING FROM THE OUTER ZONE OF FLAME.

	Luminous.			Bunsen.		
Nitrogen	76	612	...	80	242	...
Water-vapour	14	702	...	13	345	...
Carbon dioxide	2	201	...	4	966	...
Carbon monoxide	1	189	...	0	006	...
Oxygen	2	300	...	1	430	...
Marsh gas	0	072	...	0	003	...
Hydrogen	2	888	...	0	008	...
Acetylene	0	036	...	Nil.		...
	<u>100'000</u>			<u>100'000</u>		

Finally, when we use gas, the hot products of combustion collect next the ceiling, and the emanations from our body and expired air being at a much lower temperature than the products of combustion, do not rise through them, so that as far as ventilation is concerned, the ceiling is lowered to the level of the gas-burners. These considerations lead to the conviction that, for health, adequate ventilation must be allowed for the lighting arrangements as well as the inhabitants of a room, no matter what source of illumination be employed.

If candles or oil be used, all that can be done is to secure the ventilation by the ordinary methods, as the conditions under which these sources of light are employed prevent use being made of them as ventilating agents. But with gas this is not the case. The impurities in the coal gas in the early days of its introduction, coupled with the low pitch of the old-fashioned rooms, rendered it imperative to lead the sulphur-laden products of combustion from the apartment; and to attain this end funnel-shaped tubes were provided over the burners, and these carried the gases to the flue or into the open air,

The unsightly nature of this mode of ventilation led to attempts at more elegant arrangements, as in the ventilating lamp invented by Faraday. The improvement in the purity of the gas supplied of late years, together with the great increase in the height of modern rooms, rendered the products, if not less injurious, at least much less offensive to the nose.

Since this point was reached but little has been done, and from that time to this but slight efforts have been made to combat with the vitiating effect of the various illuminants upon the air of our rooms. The consumption of enormous quantities of coal gas in the illumination of theatres and all places of entertainments, made it absolutely necessary to remove the products of its combustion, and the first step in this direction was the "sun burner," with its ventilating shaft, but the illuminating value obtained per cubic foot of gas consumed in this burner is very poor, due in a measure to the cooling effect of the large volumes of air drawn up by the ventilating shaft, and also to its great distance from the objects to be illuminated.

The great obstacle which has opposed the adoption of convenient methods for removing the products of combustion, has been the necessity of bringing the tube to carry off the products of combustion low down into the room, and of encasing the burner in such a way so that none of the products should escape. But with the present revolution in burners this obstacle is now overcome, and the Regenerative burner gives not only most satisfactory lighting values, but also is most effective in the removal of the products of combustion, and moreover effects a complete ventilation of the room itself.

The conversion of a Regenerative gas lamp into a venti-

lating agent is effected by enclosing it in a metal case, which is usually enlarged and ornamented at the base so as to form a handsome centre-piece to the ceiling, and this is perforated, so as to communicate with the room, whilst the upper part of the metal case or air-box is sunk into the ceiling space, and is surrounded by an outer casing—the space ($1\frac{1}{2}$ inches) between the outer and inner casing being packed with silicate wool, which, being a non-conductor of heat and non-inflammable, prevents any risk of fire, and also keeps the outer casing from rising above a temperature of from 78° to 100° F. This air-box, which contains the Regenerative portion of the burner, is connected by a cased tube, carried through the ceiling space to a shaft passing either up the flue or to an external shaft; the heated products passing up this cause a draught, which removes not only the products of combustion, but also the heated impure air from the upper part of the room.

The heating effect produced by illuminants and the action this has upon the atmosphere must now be considered. A luminous flame, whether derived from a candle, oil, or gas burnt in ordinary incandescent or Regenerative burners, heats the air and surrounding objects in two distinct ways: (1) By convection; the hot products of combustion mingling with the cool air produce currents, and so gradually the temperature of the whole mass of air present becomes raised. (2) By radiation from the incandescent particles of ignited carbon in the flame the rays do not directly heat the air, but pass through it until it reaches some solid body which it heats, and also the water-vapour present in the air.

Now the kind of heat emitted by a gas flame depends entirely upon the conditions under which it is burning, the

amount of solid matter in the flame capable of being heated to incandescence, and the temperature to which this solid matter is heated. This may best be seen by burning a mixture of gas and air, as in the Bunsen burner, which gives a non-luminous flame and but little radiant heat, but which will quickly warm the air by convection. If a coil of platinum wire be held in the flame it becomes heated to incandescence, and gives out both light and radiant heat; and these are produced at the expense of the heat of combustion, which before was wasted in heating the products of combustion and the surrounding air. In all ordinary illuminating flames, whether from gas, candles, or oil, solid particles of carbon are present; these being highly heated and so rendered incandescent emit light and radiant heat, the carbon liberated being due to the selective combustion of the hydrogen and carbon. The hydrogen, owing to its greater affinity for the oxygen of the air, burns first, and the carbon, liberated for a moment, is heated by the burning hydrogen to incandescence.

The amount of light evolved depends entirely upon temperature; the higher the solid particles can be heated, the more light is evolved. In the Regenerative burners the hot products of combustion are made to pass up between the incoming air and gas, which so become heated to a high temperature, and in this way the heat of combustion is utilized to heat the carbon particles to the highest possible temperature, and so to obtain from them the greatest amount of light; but a certain proportion of the heat of combustion is translated into radiant heat, and the only disadvantage of this kind of burner is that when they are fitted too low down in the room they are apt to be unpleasantly hot to the head.

CHAPTER VII.

WATER AND ITS COMPOSITION.

It has already been shown how important a part was played by Priestley, Cavendish, and Lavoisier, in the discovery of the constituents of the atmosphere, and it was again to this great triumvirate of genius that the still more important discovery of the composite nature of water is to be credited.

From the earliest times our great liquid compound had always been looked upon as one of the elements, and no shadow of doubt ever arose on this subject until Priestley in one of his many works noticed the fact that when a mixture of air and the gas which we now call hydrogen was exploded by the electric spark in a dry glass vessel, the inside of the glass became coated with dew. He, however, took no further note of the phenomenon, and it was whilst working out the explanation of this experiment that Cavendish came upon the most important of the discoveries which crowned his experimental successes.

No two men could have been more unlike in their methods of working than Cavendish and Priestley; Priestley being imbued with the idea that the discovery of natural facts was best attained by rapid performance of a large

number of haphazard experiments, made at random, and more often than not leading to no result, whilst Cavendish on the other hand worked slowly and laboriously towards a preconceived end. Priestley loved turmoil and argument, and published pamphlets on every conceivable subject; whilst Cavendish, on the other hand, had a morbid dread of publicity; and it was not until after his death that a large proportion of the work which he did was ever dreamt of by the outside world, and it was to this painstaking work that we owe the discovery which will make the name of Cavendish for ever famous.

Cavendish repeated Priestley's experiment with air and hydrogen in his usual careful manner, noting the quantity of gases taken, and also the diminution in volume which in each case attended the explosion; and working in this way with carefully purified air and hydrogen as pure as he could prepare it, came to the conclusion that the greatest diminution of volume occurred when two volumes of hydrogen were mixed and exploded with five volumes of air; and in order to prove to his own satisfaction that the dew which formed and lined the inside of his vessel really was water, he devised a second experiment in which he burnt a large quantity of hydrogen gas in a large tube eight feet long and three-quarters of an inch in diameter, during the passage up which all water-vapour formed by the combustion of the hydrogen at the bottom of the tube was condensed, and ran back into a reservoir prepared to receive it.

In this way rather more than 135 grains of water were formed and condensed, and on examining this water he found that it had neither taste nor smell, and that when evaporated it left little or no sediment behind it, and answered to all the characteristic properties of ordinary

water. It was evident to his mind, from these experiments, that the water formed had arisen from the combination of the hydrogen with one of the constituents of the atmosphere ; and the next point which he set himself to solve was, whether it was the nitrogen or the oxygen of the air which had combined with the hydrogen, and he soon came to the conclusion that it was the oxygen, and oxygen only, which had done so. No sooner had he reached this point than he at once set to work to prepare mixtures of hydrogen with oxygen alone, and he found that when he made a mixture of the gases in the proportion of two of hydrogen to one of oxygen, and then exploded them in a strong glass vessel by means of an electric spark, a few drops of water were the result of the explosion ; and when the vessel was opened under the surface of water or of mercury, the liquid rushed in and entirely filled it, showing that in these proportions the two gases disappeared to form nothing but water.

Such then were the experiments which led to the discovery, first, that water was a compound and not an element ; secondly, that it was a compound of the two elements hydrogen and oxygen ; and thirdly, that when these two elements combine to form water they do so in the proportion of two volumes of hydrogen to one of oxygen.

Although Cavendish by these experiments distinctly proved these important facts, his writings seem to show that he did not himself very clearly grasp that water was a chemical compound of the two elements, a fact which was not thoroughly mastered until Lavoisier satisfactorily explained the action which had taken place ; and this explanation, which was given in 1783, may be looked upon as giving the real date of the discovery of its composite nature.

Not only can water be formed by the direct combination of hydrogen and oxygen, but a still clearer proof of its composition may be obtained by decomposing it once more into its constituent elements, and this was done by Lavoisier by passing steam over red-hot iron, when the iron decomposed the water and combined with its oxygen to form an oxide of iron, whilst the hydrogen was liberated—a process still in vogue for the preparation of hydrogen on a large scale.

Before it is possible to enter fully into the composition of water, it is necessary to study the properties of its chief constituent, hydrogen, which was probably first discovered by the alchemist Paracelsus in the sixteenth century; although it was not until Cavendish's experiments with it in 1766 that the true nature of the gas was thoroughly understood.

Practically, hydrogen does not exist free to any great extent on the earth, as with the exception of small quantities found in the gases escaping from volcanoes it is never found by itself; indeed water is the great storehouse of hydrogen; while it also occurs in combination, although in much smaller quantities, with such elements as chlorine, sulphur, and nitrogen, and forms an important constituent of nearly all organic compounds. The ordinary experimental way adopted on a small scale for the preparation of hydrogen gas is to act upon a mixture of sulphuric acid and water with zinc or iron.

Sulphuric acid is a compound built up of hydrogen, sulphur, and oxygen, and when this compound comes into contact with zinc a decomposition takes place; the zinc combining with the sulphur and oxygen of the sulphuric acid to form the compound of zinc, sulphur, and oxygen,

which is called zinc sulphate, whilst the hydrogen is set free.

Zinc is first melted in a convenient vessel, and is poured from a height of a few feet into a large vessel of cold water, the sudden cooling of the molten metal causing it to assume irregular forms, which expose a much larger surface of the metal than would have been the case had it merely been cut into slips or small blocks. This so-

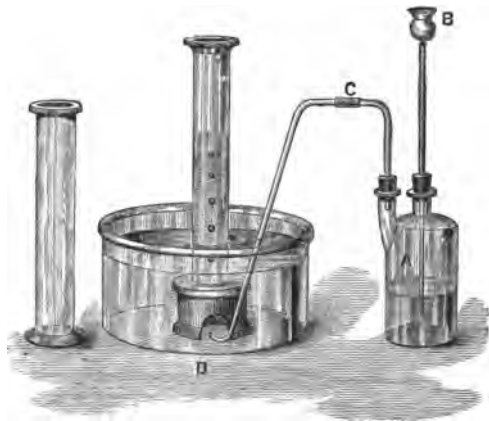


Fig. 13.

called granulated zinc is then placed in a two-necked bottle, one neck of which is closed by a cork through which a tube passes gas-tight and reaches to the bottom of the bottle, whilst the upper end is blown out into a funnel, so that any liquid poured into the funnel will flow down to the bottom of the bottle. The second neck is also closed by a cork, and through it a glass tube just passes gas-tight into the bottle, and serves as a delivery-tube through which any gas generated can be led away to the collecting-trough (Fig. 13).

Water is now poured into the generating-bottle until the zinc is well covered by it, and sulphuric acid is then added a little at a time by means of the thistle funnel. Directly the acid is added, chemical action is set up, and the metal zinc, being chemically stronger than the hydrogen, turns it out from its combination with the sulphur and oxygen in the sulphuric acid, and takes its place, forming zinc sulphate, which is at once dissolved by the water present, leaving a fresh surface of the metal exposed, whilst the hydrogen escapes and is led away by means of the delivery-tube.

In making hydrogen gas, there are several important precautions which must be observed to ensure safety. In the first place, it is most important that there should be plenty of water covering the zinc, as strong sulphuric acid in an undiluted condition has apparently no action on the zinc, as the zinc sulphate formed during the first moment being insoluble in strong sulphuric acid, coats the metal, and stops any further action. If, after adding strong sulphuric acid, water were to be poured in, the heat generated by the mixture would lead to such intensely rapid chemical action, that most of the acid liquid would be blown out of the bottle, with consequent injury of the surrounding objects. If plenty of water be present the addition of the acid little by little soon sets up a steady flow of the gas, and this gradually sweeps away the air with which the generating-bottle was originally filled, and after a lapse of from five to ten minutes the gas can be collected in a fairly pure condition.

The mixture of hydrogen and air which is at first driven out of the bottle is highly explosive, and on no account must a light be brought near the open end of the delivery-tube without first testing the gas by collecting a little in a

cylinder and seeing that it burns quietly, as should any air remain a serious explosion will result, the broken glass and sulphuric acid causing great damage.

The properties of hydrogen are so full of interest that it is as a rule the first gas which the embryo experimentalist essays to make; and the neglect of the precautions mentioned above in most cases have caused so much domestic havoc amongst curtains, carpets, and table-covers that further scientific research has been put down with a strong hand.

The pure hydrogen is a clear colourless gas having neither taste nor smell, and being practically insoluble, it may be collected and stored over water, one hundred volumes of which dissolve less than two volumes of the gas. Hydrogen burns in air or oxygen with a non-luminous but intensely hot flame, water-vapour being the only product of its combustion. It does not support combustion in the ordinary sense of the term, and a lighted taper plunged into a jar of the gas is at once extinguished. These last two properties may be both demonstrated by one experiment, for if a cylinder full of hydrogen be held mouth downwards in air and a lighted taper be then passed up into it, the hydrogen burns at the mouth of the cylinder, but the taper as soon as it enters the gas is extinguished, and can be again relighted on withdrawing it by the flame of the burning hydrogen.

The most marked and characteristic property of hydrogen is its wonderful lightness. It is the lightest gas known, and is for that reason taken as the standard to which the weights of all other gases are compared.

It is 14.47 times lighter than air, and can be easily poured upwards from one vessel into another; so that if a cylinder

full of the gas be held with its mouth downwards in air, it takes some time for diffusion to remove all the gas from the cylinder, whilst if it be placed with its mouth upwards a few seconds suffice to empty it.

The great lightness of the gas renders it very valuable for ballooning where a rapid ascent to a great height is desired ; but its very lightness is a drawback where a balloon is wanted to keep afloat for some time, as the rapidity with which the gas diffuses (see page 69) causes it to rapidly escape from any cracks or imperfections in the skin of the balloon.

A balloon full of a light gas displaces a volume of air equal to its own bulk ; and when the weight of the balloon, plus the weight of the gas which it contains, is lighter than the weight of the volume of air displaced, the balloon rises ; but inasmuch as the atmosphere rapidly diminishes in density (*i. e.* in weight) the higher one goes from the surface of the earth, a point is soon reached at which the weight of the balloon and its contained gas is equal to the weight of air displaced, and as soon as this point of equilibrium is reached the balloon ceases to rise.

If hydrogen is used to fill a balloon it gives great rising power, but the rapidity of diffusion soon brings it down again ; whilst if a long journey is required, a larger balloon filled with coal-gas would be employed, as although coal-gas is about eight times as heavy as hydrogen, still it is lighter than air in the proportions of 8 to 14.47, and the tendency to diffuse is far smaller.

At the present time great importance attaches to ballooning, from the fact that it is being adopted rapidly and on a very large scale for military and naval purposes.

A regular balloon corps is now attached to the army, and

the hydrogen is carried compressed in steel cylinders on a waggon constructed for the purpose; and the balloon when required is filled from these, and is sent up with a rope attached to it, so that when observations have been made of the enemy's whereabouts it can be again drawn down, emptied, and packed away. For ordinary purposes balloons are made of varnished silk; but the leakage from this would be too great if hydrogen were used, and the military balloons are now all made of a double thickness of gold-beater's skin.



Fig 14.

The lightness of hydrogen gives it peculiar properties with relation to sound, which travels between three and four times as fast in hydrogen as in air; but sounds generated in an atmosphere of hydrogen are almost imperceptible where they have to be transmitted from the hydrogen to air. This can be beautifully shown by ringing an electric

bell in a bell-jar of air and then passing in hydrogen (Fig. 14), when the sound becomes first shrill, and then almost inaudible; but on allowing the hydrogen to again escape, the sound once more is heard with its full intensity. This is explained by the fact that sound is transmitted through air by the vibration of the particles of which it is composed, and these being all of nearly the same weight, carry on the

vibration from particle to particle ; but the hydrogen particles being more than fourteen times lighter than the air particles, their impacts on the heavier particles are unable to set up the same rate of vibration, and this retards the transmission of the sound.

Certain metals have the property of absorbing very large volumes of hydrogen gas, and this is especially noticeable in the case of the metal palladium, which at ordinary temperatures will absorb between three and four hundred times its own volume of the gas, and having done so its physical properties are so modified that there is every reason for supposing that the gas has really alloyed itself with the metal, and the name "Hydrogenium" has been given to the compound ; and inasmuch as alloys are the feeble compounds formed by metal with metal, this property of the hydrogen points to the fact of the gas having metallic properties.

If a palladium wire, 2 ft. 6 in. long, be so arranged (Fig. 15) that it forms the negative pole in a galvanic circuit, with large glass tube as a decomposing cell (A) and a platinum wire as the positive pole, on decomposing acidulated water hydrogen gas will be evolved on the surface of the palladium, and being occluded will cause an increase in length of the wire, which will be made visible by the lever arm (B).

The metallic nature of hydrogen, although totally opposed to its physical characteristics, is unmistakably traceable in most of its chemical actions. We have seen that when steam is passed over red-hot iron, the iron displaces the hydrogen, which is set free, and combines with the oxygen to form an oxide of iron ; and we also find that if hydrogen be passed over oxide of iron heated to a dull red heat, that steam is again re-formed by the hydrogen taking up oxygen

from the heated oxide, and metallic iron is left. Here it is evident that hydrogen and the metal are interchangeable ; and a very large number of such cases incline one to the belief that our lightest of known gases really is the vapour of a metal which, however, exists as a liquid and solid at such intensely low temperatures that we have never been able to reach them.

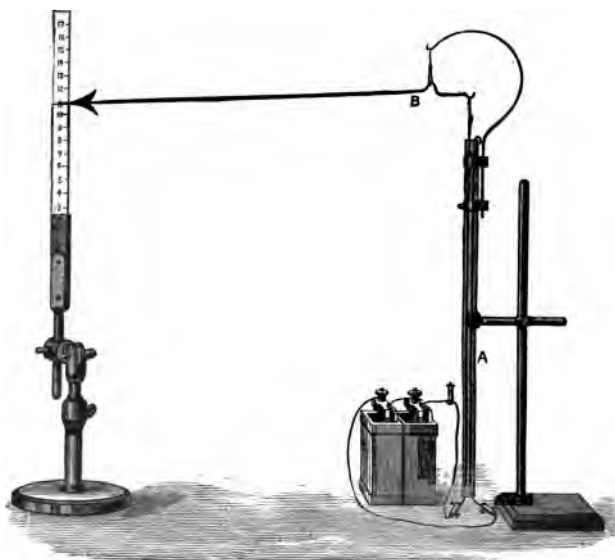


Fig. 15.

This idea has endowed with special interest the attempts made to liquefy and solidify hydrogen, as, if it could be done, the question might be set at rest. Some ten years ago it was thought that the gas had been, like all others, condensed to a liquid by the combined action of enormous

pressure and intense cold ; whilst one observer went so far as to say that on allowing the liquid hydrogen to escape into air, it resumed the gaseous state so rapidly that a cold intense enough to freeze some of the escaping liquid to the solid was produced, and that the particles fell on the stones of the laboratory with a metallic ring. More exact experiments have, however, shown that this was a mistake, as until we can obtain a degree of cold far greater than any yet reached, we shall not even be able to condense the gas to a liquid, much less to obtain the solid.

Another striking proof of the metallic properties of hydrogen gas is to be found in its behaviour during the decomposition of liquids containing it by the galvanic current.

In the galvanic battery the action of dilute sulphuric acid upon zinc is made use of to generate a galvanic current in the following way :—

During the solution of the zinc in the acid considerable heat is given out, this being due to the chemical action which is taking place, and which results in the formation of zinc sulphate ; and by connecting a plate of zinc to a plate of copper, both metals being in the same vessel of dilute acid, we can convert the heat energy into galvanic energy. If plates of these two metals are placed an inch or two apart, in a vessel of diluted sulphuric acid, and are then connected outside the liquid by a copper wire, the galvanic current flows through the wire and endows it with properties which it had not before. A battery is constructed by taking several such vessels (each of which is called a cell), and connecting together the metallic plates they contain in such a way that the zinc in one is connected with the copper in the next, by means of a copper wire. If one of

these connecting wires be now cut in the centre we should have a series of cells in connection with a free wire at each end, one connected to a copper-plate, the other to a zinc plate, and all the time these end wires are kept apart, ordinary chemical action goes on in the series of cells between the zinc and the dilute acid, and heat is evolved; but directly the terminal wires are brought in contact, the heat generated diminishes and a galvanic current is produced.

There are many forms of cells, but in all of them this same principle is used; and the metal which is acted upon is called the positive metal, whilst the unaffected metal is called the negative; and it is found that in the liquid of the cell the galvanic current flows from the positive to the negative metal, whilst in the wire outside the liquid the return current flows from the negative metal to the positive.

If we now take the two terminal wires, and instead of bringing them directly in contact, plunge the ends of them a few inches apart into a liquid which will conduct electricity, we find that the current flows from one wire to the other through the liquid, and in doing so in many cases decomposes some of it into its constituents—a decomposition of this kind being called “electrolysis.” The ends of the wires to be employed for this purpose generally have small platinum plates attached to them, as this metal is but little affected by the products liberated during decomposition. The plate in connection with the copper of the cell (the negative metal) is called the “positive pole” or electrode, whilst the plate in connection with the zinc (positive metal) is called the “negative pole,” or negative electrode.

If the poles of a strong battery be placed in almost any solution of a metallic salt, it will be found that the salt is

decomposed, and that the metal is set free at the negative pole—*i. e.* the pole where the current leaves the liquid ; whilst the element or elements in combination with the metal are set free at the positive pole—the pole where the current enters the liquid. If now water, which has been acidulated with a few drops of sulphuric acid to render it a conductor, be subjected to the action of the galvanic current it is decomposed ; oxygen coming off at the positive pole or electrode, while twice as much hydrogen by volume is liberated at the negative electrode ; and this is another most important piece of evidence as to the metallic characteristics of this wonderful gas.

CHAPTER VIII.

THE DETERMINATION OF THE COMPOSITION OF WATER.

THE first determinations of the composition of water were made as related in the last chapter by Cavendish, and his method of working was as follows :—

He took a strong glass vessel (A) closed at the lower extremity by a stopcock (B), and at the upper end by a stopper (C), through which passed, gas-tight, two wires which came close together in the interior of the vessel, but did not touch ; and by connecting these two wires to the poles of an induction coil or a Leyden jar, a spark could be made to leap across between the ends of the wires in the vessel, and so cause the combination of any explosive mixture which might be in it, the vessel being at the same time sufficiently strong to bear the shock of the combination without danger of fracture.

Having carefully exhausted all the air from A by means of an air-pump, it was attached to the receiver D, containing a mixture of oxygen and hydrogen in known proportions, standing over water in the vessel E. Some of the mixture was then admitted to the vacuous vessel A by opening the stopcock B, and exploded by passing a spark through it, this causing a combination of the hydrogen and oxygen to form water (Fig. 16) ; and by repeating this operation, Cavendish found that if he had a mixture of exactly two volumes of hydrogen and one of oxygen, he could convert the whole of it

into water, and at the end of the operation have just as good a vacuum in A as he started with; and from this he rightly assumed that hydrogen and oxygen combine in the proportions of two volumes of hydrogen to one of oxygen to form water.

This apparatus is known as Cavendish's Eudiometer, and the name is still retained for the more accurate instrument that is in use at the present time for synthetically determining the proportions in which gases combine during explosion.

This consists of a straight tube of convenient length (A, Fig. 17), closed at one end and open at the other, and very carefully graduated throughout; at the closed end two platinum wires are fused through the glass, and terminate about $\frac{1}{16}$ of an inch from each other within the tube, whilst outside they are generally curled into loops.

Platinum can be sealed through glass in this way, as they both have the same co-efficient of expansion and contraction, *i. e.* they expand with heat and contract on cooling at the

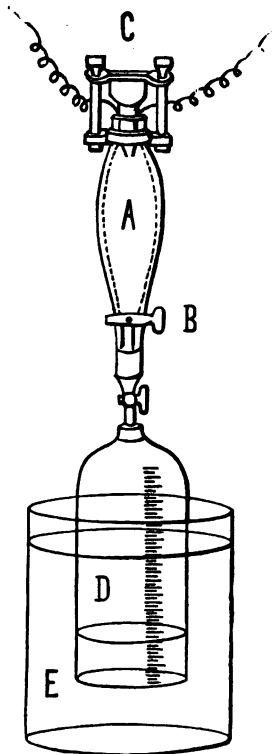


Fig. 16.

same rate ; if copper-wire were to be sealed through glass the metal would contract faster than the glass, it would crack away from it on cooling.

In order to determine the composition of water in such an apparatus, we should first fill the eudiometer with water or mercury, and have it standing mouth downwards in a

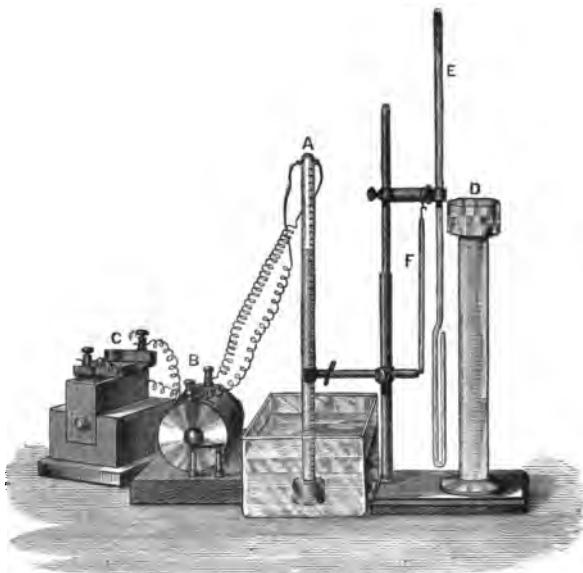


Fig. 17.

trough of the same liquid ; some pure hydrogen would then be bubbled up into the tube, and the volume so admitted carefully measured by removing the eudiometer and its contents to a deep vessel called a well (D), in which the eudiometer tube can be depressed until the level of the liquid both inside and outside the tube are equal ; the volume of

the gas in the tube is then read off by a sort of telescope called a cathetometer, which enables one to read the graduations on the tube without approaching so near it as to affect the temperature of the gas by radiation from the body. The eudiometer is now removed to the trough and some pure oxygen is admitted, the volume of mixed gases being read off as before.

We now know the volumes of oxygen and hydrogen present in the tube as a mechanical mixture, and removing the eudiometer once more to the trough, the platinum wires are connected with the poles of an induction coil (B); and having pressed the open end of the tube firmly down upon a pad of indiarubber to prevent any gas being blown out of the tube during combination, a spark is made to pass from wire to wire; this causes the oxygen and hydrogen to combine, and a flash is seen to pass down through the gases in the tube, and on lifting it from the pad, the liquid rushes up the tube and nearly fills it; the uncombined gas which is left being the excess of either oxygen or hydrogen. This is now measured and tested by applying a light to it; if it is hydrogen it will burn in contact with air; if oxygen, it will increase the rapidity of combustion of the taper, and we have now all the data we require.

Volume of hydrogen taken = say ... 23 vols.

Volume of oxygen and hydrogen = ... 38 vols.

\therefore Volume of oxygen = $38 - 23$ or ... 15 vols.

After explosion 3.5 volumes of oxygen left.

Hence 23 volumes of hydrogen have combined with 15.3.5 or 11.5 volumes of oxygen to form water; or in the ratio of two volumes of hydrogen to one of oxygen.

During the experiment any change of temperature or pressure in the air of the room in which the operation is

carried on is carefully noted, and the volumes of gas taken are corrected for these variations.

In these experiments the gases have combined first of all to form water-vapour, which has at once condensed to the liquid state, in which it only occupies $\frac{1}{1700}$ of the volume of

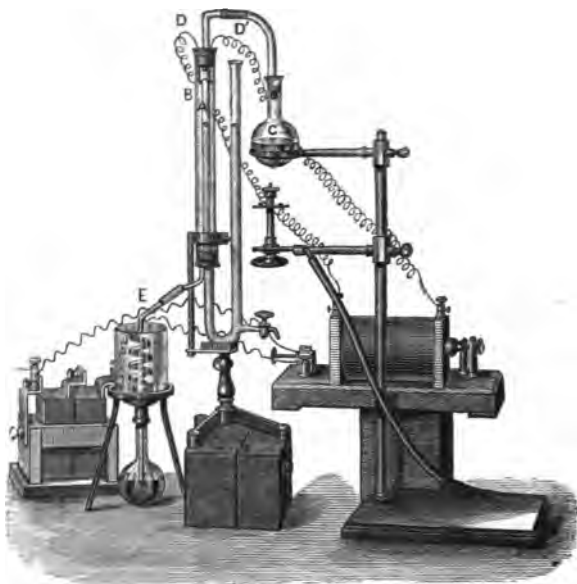


Fig. 18.

the vapour ; but if the operation had been performed over mercury, and the tube and liquid had been kept at a sufficiently high temperature to prevent the condensation of the water-vapour, it would have been found that three volumes of the mixture of oxygen and hydrogen had formed two volumes of steam on combining ; *i. e.* that when two volumes

of hydrogen combine with one of oxygen to form water-vapour there is a contraction of one-third in volume (Fig. 18).

To do this the eudiometer (A) is surrounded by a wide glass tube (B); exactly two volumes of hydrogen and one of oxygen are placed in the eudiometer over mercury, and amyl alcohol (fusel oil), which boils at 128°C ., is then vaporized in the flask (C), and is passed through the outer tube (B), and is condensed in the worm (E). This heats the gases and mercury in the eudiometer to a temperature

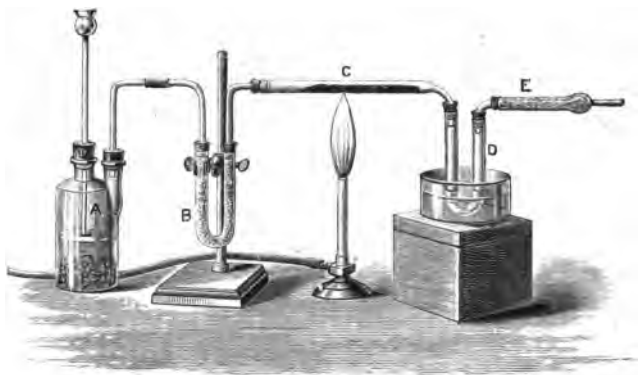


Fig. 19.

several degrees above the boiling-point of water, and if a spark is now passed through the mixed gases, a contraction exactly equal to one-third of the volume takes place.

The composition of water by weight is determined accurately as follows: Hydrogen gas is prepared by the action of zinc on dilute sulphuric acid, and is then passed through a series of wash-bottles to purify it from all traces of foreign gases which might be present, and finally through tubes containing fused chloride of calcium, a salt which has

a great power of taking up moisture, and which thoroughly dries the gas. The dry pure hydrogen now passes over some oxide of copper in a bulb tube, the weight of tube and oxide having been first carefully determined; and on heating the oxide of copper the hydrogen decomposes it, taking the oxygen from it and combining with it to form steam, which passes on and is absorbed in a series of carefully weighed chloride of calcium tubes (Fig. 19).

The oxide of copper having lost oxygen, some of it is now in the metallic state, and the tube containing it will weigh as much less as there has been oxygen used up. On the other hand, the chloride of calcium tubes which have absorbed the steam formed during the experiment will weigh more, and their increase in weight will give the *weight* of water formed by the *weight* of oxygen lost by the oxide of copper, and the difference between these two weights will be the weight of hydrogen which has entered into combination. For example:—

Weight of tube with oxide of copper before experiment	=	67.75	grs.
" " with reduced copper after experiment	=	64.55	
∴ Weight of oxygen used up during experiment	=	3.20	
Weight of chloride of calcium tubes before experiment	=	127.82	
" " after experiment	=	131.42	
∴ gain in weight due to water formed	=	3.6	
but oxygen used to form water	=	3.2	
∴ Hydrogen used	=	.4	

And from this it is evident that the oxygen and hydrogen have combined in the proportions of 3.2 to .4; or in other words, that nine parts by weight of water contain eight parts by weight of oxygen and one of hydrogen.

So far the methods described for determining the composition of water by volume and weight have been synthetical, *i. e.* have depended upon a building up of the compound from its constituents; but the same results are arrived at by

processes of analysis, *i. e.* breaking up the compound, and ascertaining the proportions in which the constituents are liberated.

If we take water and, having converted it into steam, pass it over iron heated to dull redness, we find that it is broken up into its constituents, the oxygen remaining combined with the iron, whilst hydrogen comes off free, and may be collected by suitable arrangements. Iron is not the only

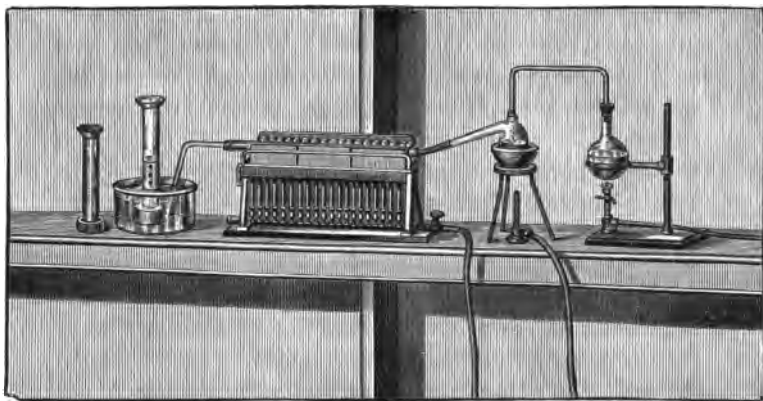


Fig. 20.

metal which will do this ; indeed, certain metals like sodium and potassium will decompose water at ordinary temperatures, whilst magnesium only requires a temperature of 100° C. to effect the decomposition. The fact that we can obtain hydrogen gas from steam proves that hydrogen is one of the constituents of water ; and we also find that if a mixture of steam and chlorine be passed through a heated porcelain tube, the steam is decomposed, the hydrogen and

chlorine uniting to form hydrochloric acid whilst oxygen is liberated.

This is best done by generating chlorine gas by gently warming a mixture of hydrochloric acid and black oxide of manganese in the flask (Fig. 20), and leading the liberated chlorine through water in the retort, which is kept just at the boiling-point by a water bath; the chlorine so saturated with water-vapour is then passed through a porcelain tube heated to dull redness in the gas furnace—a larger heating surface being obtained by filling the tube with pieces of broken porcelain or glass; under the influence of heat chlorine decomposes water-vapour, and the resulting oxygen and hydrochloric acid, together with any chlorine or steam which may have been in excess, pass on, and if they be led into water in the pneumatic trough and collected by displacement of water in the cylinder, the chlorine and hydrochloric acid, being soluble, will be absorbed by water, any steam will be condensed, and nothing but oxygen remain.

If water, slightly acidulated with sulphuric acid to render it a conductor, has a galvanic current passed through it, in the way described in the last chapter, the oxygen is liberated at the positive pole where the current enters the liquid, and the hydrogen at the negative pole where the current leaves; and by placing receivers over these poles the gases can be collected separately, when it will be found that there is a little more than twice as much hydrogen as oxygen evolved, the slight discrepancy being due to oxygen being slightly more soluble than hydrogen, and also to the fact that during electrolysis some of the oxygen evolved is converted into ozone (Fig. 21).

The rapid combination of oxygen and hydrogen is accompanied by a feeble light and by a great development of

heat, and is used to produce the highest temperatures attainable by chemical combination on a practical scale.

When one of the gases merely flows into the other during combustion, a perfectly quiet but extremely hot flame is produced where the surfaces of the gases are in contact; but if the gases are mixed together before combustion, the combination takes place throughout the mass almost instantaneously, and the heat of combustion causes so enormous an expansion of the water-vapour formed, that we have the phenomenon known as explosion produced.

When a hydrogen flame burns in air, the temperature produced is about 1611°C. , but if the flame is fed with oxygen instead of air, it produces a temperature of 3148°C. ; and this fact is taken advantage of in the oxy-hydrogen blow-pipe, which consists of

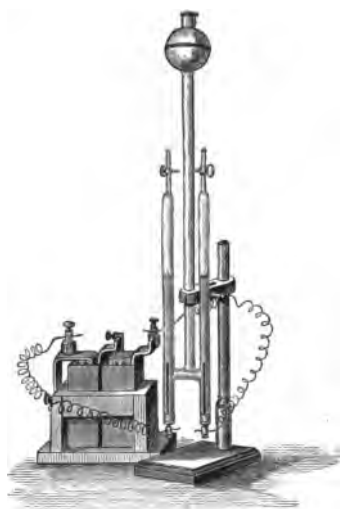


Fig. 21.

an outer tube and nozzle, at which hydrogen burns with its characteristic non-luminous flame, whilst by means of a small inner tube, the flame during combustion can be supplied with oxygen, which causes it to lengthen out into a thin pointed flame, capable of burning away steel as if it were so much tinder, and raising non-combustible bodies like lime to an intense incandescence.

Between the explosive combination of oxygen and hydrogen, and its quiet burning with generation of intense heat, we have an intermediate class of phenomena known as chemical harmonica or singing flames.

If hydrogen be quietly burning at a steady rate of flow from a small jet, and a wide glass tube be depressed over the flame, a continuous musical note is frequently produced, a phenomenon explained by Faraday, who found it to be due to the glass-tube acting as a shaft or chimney-glass, and so causing the rapid passage of a current of air up the heated tube; this impinges on the flame of hydrogen, and as there is more oxygen than is required for quiet combustion, a number of small explosive mixtures are formed round the flame, and by their rapid detonations set up a constant vibration which gives the note. During this action the flame, which had originally the elongated pear-shape of an ordinary flame burning at a small nozzle, becomes distorted and elongated, the small explosions indenting the side of the flame, and sometimes even blowing it out.

The notes obtained in this way are not very loud, but an intense shrieking note can be easily obtained by drawing out a glass-tube into a fine jet, and attaching it by a piece of flexible indiarubber tubing to a gas supply, where the gas will burn at the jet with a long flame. If now a piece of fine wire-gauze be taken, and the flame be held under it, it will be seen that the flame does not pass through, as the metal of the gauze conducts away the heat so rapidly from the flame that it puts it out; in the same way if the jet be extinguished and held under the gauze, the gas may be ignited above without passing through to the jet below.

Now put the square of wire-gauze on any convenient holder, and stand a lamp-glass on it; place the jet under

the gauze, and ignite the gas which has passed through inside the lamp-glass; on now lowering the jet from the gauze, the gas will in passing up carry with it air, and when a certain point has been reached, a strong shrieking note will be produced, varying in intensity with the size of the lamp-glass.

In all cases where hydrogen burns in oxygen, or feeble compounds of oxygen which can be easily decomposed, water-vapour is formed, and it is also one of the products of combustion of substances containing hydrogen.

CHAPTER IX.

THE PROPERTIES OF WATER.

PURE water is a liquid having neither taste nor smell, and when seen in small quantities appears colourless, but on looking through a large volume it is seen to be of a greenish-blue colour. The colour varies according to the purity of the water, from pure green to blue, and the colour is not only noticeable in deep clear lakes, but also in masses of ice.

The relations of water to temperature are amongst the most wonderful and important of its properties; it is indeed the great climate-maker; the presence or absence of water making an incalculable difference in the ranges of temperature to be found in different countries.

Water has the power of absorbing more heat in order to raise it through any given range of temperature than any other known substance, and the result is that it can absorb a very large amount of heat, without itself undergoing any very great increase in temperature.

The amount of heat required to raise a unit weight of water one degree is called its specific heat, and water being taken as unity, the specific heats of various substances are all less than 1. For instance—

SPECIFIC HEATS OF SOLIDS AND LIQUIDS.

Alcohol	0'615	Copper	0'095
Ether	0'516	Silver	0'057
Sulphuric acid	0'333	Mercury	0'033
Carbon	0'241	Tin	0'056
Sulphur	0'202	Gold	0'032

—so that a given weight of alcohol could be raised 1° in temperature by 0'6 of the heat required to raise an equal weight of water the same degree, whilst one pound of mercury would only take 0'032 the heat required by a pound of water.

The result of this great capacity for heat is, that as the summer sun beats down upon large masses of water heat is slowly absorbed, and stored up without the water itself becoming unduly heated, and then as summer slowly gives way to winter and the temperature falls, this store of heat is again slowly given off, checking the too sudden inroads of cold, and tempering the climate.

Take, for instance, the temperatures of our south coast. At Bournemouth or the Isle of Wight it may be hot in the summer, but never unbearably so, because the excess of heat is taken and is stored by the water around, whilst in the winter the giving up of this stored heat prevents any intense cold. Now, follow the latitude of Bournemouth round the globe, and you will find it leads you not far from Moscow. Consider now the temperature existing there. In summer the heat is so intense that grapes ripen rapidly in the open air, and protection against sunstroke is needed, whilst in the winter you have the almost Arctic conditions which wrecked Napoleon's great army, and which renders fur-lined coats and nose-protectors a necessity.

This enormous difference is entirely due to the presence of large volumes of water in the one locality, and the comparative absence of this great climate-temperer in the other. One cubic yard of water in cooling through one degree, warms 3076 cubic yards of air through four degrees.

When water has had its store of heat gradually withdrawn by the increasing cold, when the top layer is at a temperature of 0° C. it is converted into ice, and during this change of state from water into ice, or from ice into water, a fresh set of phenomena occurs. Take two glass beakers of exactly the same size, and place in one a pound of water at 0° C., and in the other a pound of ice at 0° C. We can obtain them both at the same temperature, as 0° C. is a border line in temperatures as regards water, being the point at which water freezes to ice, or ice thaws to water, so that ice on the point of thawing, and water on the verge of freezing, both are at 0° C. In each beaker now place a carefully graduated thermometer, and stand both beakers in an oil-bath or water-bath, so that they shall be equally heated. At once the thermometer in the beaker of water commences to register an increase of temperature; but on turning to the thermometer in the ice we find that no such increase is shown, and the mercury stands at 0° C. until the last particle of ice has assumed the liquid form. Then and then only does the heat which is being poured into the liquid begin to raise its sensible temperature.

At the moment when the last particle of ice has disappeared, look quickly at the thermometer in the first beaker, and you will find that it has attained a temperature of 79° C., or in other words it has taken as much heat to convert one pound of ice at 0° C. into water at 0° C. as

would raise one pound of water from 0° C. to 79° C., or 79 lbs. of water from 0° C. to 1° C.

The amount of heat required to raise a unit weight of water from 0° C. to 1° C. is called a "thermal unit," and we say therefore that the amount of heat used up in melting our unit of ice, without giving rise to any sensible increase in temperature, is 79 thermal units.

These 79 thermal units have done the work of bringing about the molecular change from the solid to the liquid state; and in the liquid this heat will remain stored until the water is again frozen; and then with the change back to the solid state this heat is again converted into sensible heat, which can be detected by the thermometer.

The heat taken up in this way during the thawing of ice exercises an important influence on surrounding objects, and the melting of one cubic yard of ice cools 21,000 cubic yards of air down 11° C., or from 52° F. to 32° F., so that the effect of a thaw is always to impart cold rawness to the air.

Heat which is in this way stored up during change of state is somewhat improperly called "latent heat," and it is to this rendering of heat latent that we owe most of our freezing mixtures.

For instance, if snow or powdered ice be mixed with salt, it is caused to rapidly melt, and has to obtain the heat required for this change from the surrounding objects, so that if a vessel containing water be placed in the mixture, the heat is withdrawn and the water is frozen.

Nearly all substances expand when heated, and contract when cooled, but between 4° C. and the freezing-point, water is an exception to the rule.

If water be taken at the boiling-point and is then allowed

to cool down, it contracts evenly in volume for each degree fall in temperature until 4° C. is reached, and at this point any decrease in temperature causes expansion. This holds good until the freezing-point is reached, and then with the conversion of the water into ice, a sudden and much greater expansion occurs, and ten gallons of water form eleven gallons of ice.

This slight variation from the usual behaviour of matter again exercises a vast influence upon our life and comfort. In the cooling of a lake or pond, the top layer of water in contact with the air cools first, and contracting becomes heavier than the water below, and sinks, its place being taken by warmer water from below, which in turn cools and sinks; this going on until the whole of the water is cooled to 4° C. When this point is reached, any further cooling of the surface causes the water to expand and become lighter than the water below, and therefore to float on the surface, until the cold has become sufficiently intense to convert the top layer into ice, which on account of the still greater expansion which then takes place floats with considerable buoyancy; and water being a bad conductor of heat, the lower depths of the pool never become cooled below 4° C., even in the most intense winter, a temperature at which fishes and aquatic plants can comfortably exist. If water did not expand on cooling below 4° C. the depths of a lake would be the coldest part, and eventually the water would freeze throughout its entire mass, killing off all aquatic life; whilst on the return of summer the sun's rays would thaw the top layer of ice, but owing to the bad conductivity of the water would never do more than liquefy the ice near the surface, so that through the hottest summer these masses of ice would remain; and as the soil is often

full of water at a certain depth, there would be a permanent mass of ice a few feet below the surface, and the presence of this great cooling influence would reduce our present climate to one of unbearable severity.

The sudden expansion due to the conversion of water into ice is a frequent cause of the bursting of water-pipes during severe frost. Pipes are left full of water and often under pressure, and when the water freezes, the sudden expansion bursts the pipe at its weakest point. The damage, however, is only discovered when the thaw comes, and the ice melting allows the outrush of the water. Leaden water-pipes are made perfectly cylindrical in order to give them the greatest carrying capacity; but if they were made oval instead of round, when the water froze it would by its expansion make the tube cylindrical, and so make room for the surplus.

This can be done by slightly flattening any outside pipes which are likely to be exposed to frost, by light blows with a wooden mallet, and when after a frost they are seen to have been again blown out to their usual rotundity, they can again be flattened preparatory to the next fall of temperature.

When water is heated above 4° C. it expands equally for each increment of temperature; and as it also expands when the temperature falls below 4° C., it is manifest that a given volume of water measured off at this temperature will weigh more than if measured at any other, and for this reason 4° C. is called the point of maximum density of water.

When water is heated from 0° C. a thermometer placed in it registers the increase of temperature until 100° C. is reached, and then under ordinary atmospheric conditions the water begins to boil and steam is evolved, and as long as that steam is allowed to escape unchecked from the

surface of the water, no further increase of temperature will be registered by the thermometer. If the heat be doubled or trebled under the vessel in which the water is boiling, the rate of emission of steam will be increased, but no increase of sensible heat is recorded by the thermometer until the whole of the water has been converted into steam. Here again we have the change of state—the conversion of the liquid into the gaseous steam—accompanied by the disappearance of heat, and as in the case of the melting of ice into water, this heat remains in the steam until it is again condensed back to the liquid state, when the latent heat once more appears as sensible heat.

If steam be passed into cold water it condenses, and giving out the stored-up heat within it rapidly causes the water to boil; and it is found that where a unit weight of steam at 100°C. is condensed into a unit weight of water at the same temperature, enough heat is given out to raise 536 unit weights of water from 0°C. to 1°C. , and we therefore say that the latent heat of steam is 536 thermal units.

This property has several industrial applications, and liquids which it would be injudicious to boil directly by fire, are often heated to ebullition by placing in them a coil of pipe through which steam is passing, the condensation of which rapidly brings them to the required temperature.

The conversion of water into vapour goes on at all temperatures; but the rapid evolution of steam only takes place when the elastic force of the vapour is sufficient to lift the atmospheric pressure on the surface of the liquid, which, as we have seen, amounts to 15 lbs. on the square

inch (p. 7), and when this happens the boiling-point of the liquid is said to have been reached.

The boiling-points of liquids vary with the properties of the substance, some of the more volatile boiling at very low temperatures, whilst others boil at temperatures far above that of water.

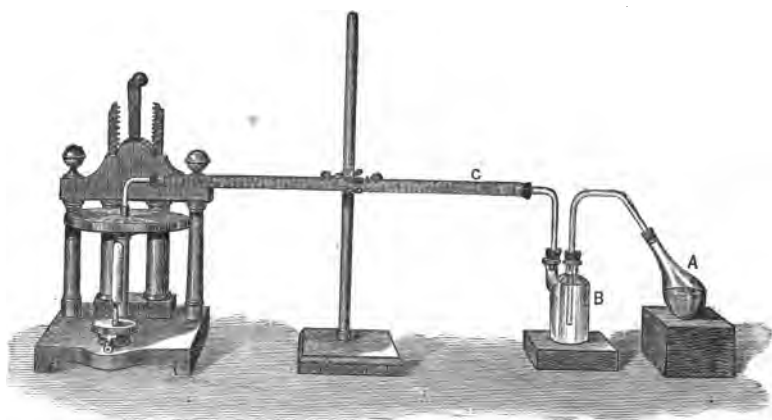


Fig. 22.

TABLE OF BOILING-POINTS AT NORMAL ATMOSPHERIC
PRESSURE.

Ether	... 35° C.	Turpentine	... 160° C.
Alcohol	... 78° C.	Sulphuric acid	... 327° C.
Water	... 100° C.	Mercury	... 350° C.

It is evident, if the boiling-point of a liquid is dependent upon atmospheric pressure, that if this be reduced the boiling-point will be lowered, or if it be increased, the boiling of the liquid will only take place at a higher temperature.

This may be shown by warming water to about 80° to

90° C. in a flask (A, Fig. 22), and attaching it to an air-pump; an empty bottle (B) and a long tube filled with calcic chloride (C) being interposed in order to condense and absorb water-vapour, and so preventing any reaching the air-pump. On giving a few strokes of the air-pump, the pressure is reduced on the surface of the water in the flask, and the water boils briskly, and this can be repeated until the temperature of the water has fallen so low that the flask can be comfortably held in the hand. Again, if a flask of water be kept boiling for some little time, so as to expel all air, and then be corked up whilst steam is still escaping, the water is left with an atmosphere of steam above its surface, and on condensing this, by pouring some cold water over it, a partial vacuum is formed, and the water once more boils vigorously. It has been seen that as we ascend a mountain the barometer gradually falls, because the higher we get the less is the atmospheric pressure; and we find that the boiling-point of water is lowered by about 1° C. for every 1000 feet we ascend, so that on the top of Mont Blanc the water boils at so low a temperature that it is impossible to make good tea or properly boil eggs. If water be confined in a perfect vacuum, or even in the vacuum to be found in the little scientific toy called the "water-hammer," it is quite possible to boil it by the heat of the hand.

This principle is employed in the sugar-refiners' vacuum-pan. Crude sugar is sent to this country, and after having been dissolved and the solution decolorized by filtration through animal charcoal, the liquid has to be again concentrated to the point at which it will deposit the small white crystals, which agglomerated together give us the white loaf-sugar. To boil off the water at the ordinary boiling tempera-

ture would be impossible, as the syrup would, to a certain extent, decompose, with formation of a brown treacle-like mass, which would not only spoil the colour, but would not crystallize. In order to overcome this trouble, the syrup is put into a boiler to which is attached a strong air-pump, and the atmospheric pressure having been reduced, the liquid is boiled down to a sufficient degree of concentration by a stream of hot water or steam flowing through a jacket which surrounds the lower portion of the boiler or vacuum-pan, and in this way the temperature is prevented from ever reaching a point at which any darkening of the syrup could take place.

If instead of decreasing the pressure on the surface of the liquid, it be increased, the boiling-point at once becomes higher, as the work to be done by the rising vapour becomes greater; so that if water be taken down a mine, the boiling-point rises in a more rapid ratio than it fell when ascending a mountain, because the difference in altitude is taking place in a denser atmosphere.

The effect of pressure in raising the boiling-point is seen in the high-pressure boilers, in which the temperature of the water and steam are far above 100° C.

In the following table the influence of pressure expressed in atmospheres (1 atmosphere = 15 lbs. on the square inch) is well shown (see p. 132).

A domestic application of this principle is to be found in the "Papin's digester," which is practically a strong iron saucepan, fitted with a steam-tight lid and safety-valve, which is loaded so as to give the desired internal pressure in the pot by preventing the escape of the steam, and so raising the boiling-point of the water.

Such an apparatus as this could be used at great altitudes

to restore the boiling-point of water to the normal temperature ; but is more often employed to raise the boiling-point for a specific purpose, when it is required to heat substances in water to temperatures above 100° C. If, for instance, in making soup, bones are boiled in water at 100° C., it is merely the meaty matter clinging to the bones which is extracted by it ; but if, by using a digester, the boiling-point is raised a few degrees, the ossein, or soluble organic matter in the bones is dissolved out and forms gelatine, which gives body to the soup and causes it to set into a jelly on cooling.

Pressure in atmospheres.	Boiling-point in degrees Centigrade.	Pressure in atmospheres.	Boiling-point in degrees Centigrade.
1	100	12	190.0
1.5	112.2	14	197.2
2	121.4	16	203.6
3	135.1	18	209.4
4	145.4	20	214.7
5	153.1	25	226.3
6	160.2	30	236.2
7	166.5	35	244.8
8	172.1	40	252.5
10	181.6	45	265.9

Although water does not boil under ordinary conditions of atmospheric pressure until the tension of its vapour is equal to the pressure of the atmosphere upon its surface, yet we find that even at temperatures below the freezing-point it slowly evaporates, as is shown by the gradual evaporation of water left exposed to air in a saucer, and even by the gradual disappearance of snow. This used to be explained as being due to the air having the power of dissolving water ; but it can be shown that air has nothing to do with it, as water will evaporate just as well into a vacuum, the property being due to the elastic force of the

vapour, a subject which will be fully discussed in the next chapter.

When water is thrown upon a heated silver dish it is seen to assume a spheroidal form and does not boil, although the plate or dish is heated very far above its ordinary boiling-point. If the dish be now allowed to cool, at a certain point the water suddenly bursts into violent ebullition and is converted into steam. This spheroidal form is due to the generation of a cushion of steam between the water and the heated surface, which prevents the water coming in contact with it, so that it only slowly evaporates; but on allowing the temperature to fall, a point is reached when the heat is no longer sufficient to rapidly generate the steam which supports the water like a cushion, the water comes in contact with the hot plate, and in a moment is converted into steam.

This has been shown to hold good in the case of boilers, so that if a boiler has been allowed to run dry and the plates have been highly heated, on the entrance of feed-water the first portions assume the spheroidal state, but as more water is added, the plates are gradually cooled, and contact takes place with formation of enough steam, in many cases, to cause explosion.

A valuable property of water is its incompressibility. Indeed for a long time it was supposed that water could not be compressed at all; but it has been shown by very delicate instruments that slight compression does take place, a fact which was first demonstrated by Oersted.

This property is of great value in the hydraulic press, in which the pressure exerted on a small piston is transmitted to a larger one, so that enormous pressure can be applied over a large surface.

We have seen that at 4° C. water is in its densest condition, and at this temperature it is taken as the standard with which the weights of all other solids and liquids are compared, and the weight as compared with an equal bulk of water is called the specific gravity of the body, so that when we say that iron has a specific gravity of 7.8, it is meant that if a given volume of water at 4° C. weighs 1, the same volume of iron will weigh 7.8 times as much.

As a neutral solvent water is unsurpassed, it dissolves all gases to a greater or less degree. If no chemical action takes place between the gas and the water, the amount absorbed depends upon—(1) the nature of the gas; (2) the temperature of the water; and (3) the pressure under which the absorption is effected.

1. Some gases are much more soluble than others; a given volume of water at 0° C. will dissolve 1149 times its own volume of ammonia gas, but only .019 of hydrogen.
2. The cooler the liquid the more gas will it dissolve; hydrogen, however, is an exception to this rule, as between 0° C. and 25° C. water dissolves .019 of its own volume of the gas without regard to temperature.
3. The volume of the gas absorbed varies directly as the pressure; that is to say, at all pressures the water absorbs the same volume of gas, but the volume of the gas varies inversely as the pressure.

This is taken advantage of in the manufacture of aerated waters. Carbon dioxide gas is absorbed by water under pressure, the amount dissolved depending upon the pressure; this pressure is then kept constant by the bottle being corked and wired, but when the cork is removed the liquid is now under ordinary atmospheric pressure, and can only

hold in solution the volume of gas corresponding to that particular pressure, the excess escaping and causing the effervescence.

The solution of solids, like the solution of gases, depends largely upon the nature of the solid; 1 litre of water will dissolve 0.14 grams of strontic sulphate, and nearly 1000 grams of magnesian sulphate.

The rate of solution is affected by the fineness of division and by agitation of the liquid, as, if the liquid be quite still, the layer of water next the solid becomes saturated, and being therefore denser protects the remainder, solution only proceeding by liquid diffusion, a process infinitely slower than gaseous diffusion.

The solubility of a salt, as a rule, increases with the temperature of the water, but strontic sulphate and lime are exceptions, being more soluble in cold than hot water.

When a point is reached at which no more of the solid can be dissolved, the liquid is said to be saturated, and if allowed to stand so that the water can cool or evaporate, the solid will again separate out—often in the crystalline form, and this form is in many cases due to water held in a feeble state of combination, and called water of crystallization. For instance, sodium carbonate crystallizes with 10 molecules of water of crystallization, and these crystals when exposed to air effloresce, that is, give off some of their water, and crumble down to a white powder.

The solution of a solid in water is generally accompanied by a lowering of temperature, caused by the conversion of sensible into latent heat, when the substance passes from the solid to the liquid state; this absorption of heat is used in many freezing mixtures, in which, by increasing the rapidity of solution of one of the ingredients, so much heat

is suddenly withdrawn as to freeze water in a vessel placed in immediate contact with the mixture, and in the same way when the substance crystallizes, the heat so rendered latent reappears. In the case of some oxides and anhydrous salts, solution is accompanied by a rise in temperature ; and this is caused by the water forming a definite combination, heat being generated by chemical action. When many oxides of the metals are brought in contact with water they combine with it, forming a body called a hydrate, and this combined water is called "water of hydration."

CHAPTER X.

THE CIRCULATION OF WATER IN NATURE.

So far we have only considered the formation and properties of water, and we have now to trace the wonderful work which it has to do in Nature, and see how this marvellous compound not only cleanses the face of the earth and keeps it in a fit condition for our habitation, but also is the greatest factor in regulating the temperature, and also in bringing about changes on the face of the world itself.

As was shown in the last chapter, water boils and is rapidly converted into steam under ordinary atmospheric conditions at a temperature of 100° C., but at all temperatures slowly evaporates into the air as vapour, the rate of evaporation becoming more rapid the higher the temperature, and this is explained by what is called the tension of aqueous vapour. If a few drops of water be passed up into the Torricellian vacuum of a mercury barometer, the mercury falls to a certain extent, and the higher the temperature the greater will be the depression, until at 100° C. the mercury inside the tube will stand level with the mercury outside—that is to say, at 100° C. the tension of the aqueous

vapour is equal to the atmospheric pressure, and it is therefore at this particular temperature that boiling commences.

The fact, however, that even at ordinary temperatures water above the mercury column causes a depression, shows that it has a certain tendency to volatilize, and it is this power which causes it to evaporate at all temperatures. When water boiled and was converted into steam, we saw that a large amount of heat was rendered latent, *i. e.* disappeared as sensible heat, because it was doing the work of keeping the particles of water in the state of vapour ; and no matter how low the temperature may be at which water is converted into vapour, it takes up and renders heat latent.

This may be very beautifully shown by what is called "Wollaston's Cryophorus," which consists of a broad tube with a bulb at each end, one of which is partly filled with water, the space above the water being a vacuum as far as air is concerned, only containing water vapour ; if the upper bulb be surrounded with a freezing mixture, it condenses some of the vapour, and the water in the lower bulb at once commences to evaporate, and thus supply more vapour to take the place of that which had been condensed ; and if the water in the lower bulb be surrounded with cotton wool, to prevent its obtaining heat from the air, so much is abstracted from the water that it is quickly frozen.

The fact that heat is taken up during evaporation can be readily proved by surrounding the bulb of a thermometer with muslin or thin linen, and plunging the bulb into a tumbler of water which has been standing for some time in the room, it will be found that the water has the same temperature as the air ; but if now the thermometer be withdrawn from the water and exposed to the air, the evaporation from

the wet muslin will cause a cooling and consequent fall of the thermometer, and the more rapidly the water evaporates, the more rapid and greater will be the cooling effect. The heat so absorbed has no effect in raising the temperature of the vapour formed, which is no warmer than the water from which it has risen, but when this vapour again assumes the liquid state, this latent heat will once more appear as sensible heat, and will increase the temperature of surrounding bodies.

A moment's consideration of every-day facts will at once illustrate the importance of this. If we get our clothes wet, it matters but little if we are taking active exercise, and ill effects rarely follow, because the exertion we are undergoing keeps the body so warm that there is enough to keep the frame at its usual temperature, and also to supply the amount taken up during the evaporation of the moisture; but if the body be at rest, then this evaporation lowers the temperature of the body itself below the normal point, and chills and illness are nearly sure to follow, and for this reason wet clothes should be changed the moment active exercise ceases. If one went to sleep with a strip of wet linen round the throat, the consequences would be most serious; but if the strip of wet rag had a piece of oil silk over it to prevent evaporation, you have one of the most effective forms of compress.

All liquids during evaporation take up heat, although not to the same extent as water, and with those that evaporate more rapidly than water, great cold may be produced. We all know how cooling and refreshing it is to have diluted scent or toilet-vinegar sprayed upon the hands and face in hot weather, whilst if the rapidly-evaporating liquid ether be used, the cold is so intense that if the spray be kept playing

on one spot for some moments, that particular spot is numbed, and rendered insensible to the pain of small operations.

In hot climates cooling by evaporation is largely utilized in order to obtain water for drinking purposes at a sufficiently low temperature to prove refreshing, and this is done by hanging up the water in unglazed earthenware vessels or water-skins, which, being porous, allow the water to very slowly exude on to the outside, where it rapidly evaporates, causing a considerable fall of temperature in the body of water inside the vessel; so that, notwithstanding the temperature being as high as perhaps 45°C . (113°F .) in the shade, water may in this way be obtained at a temperature twenty degrees cooler.

It is evident that if water evaporates more rapidly when the temperature is high, air in contact with water will be more highly charged with water vapour when warm than when cool, and if warm air be cooled a few degrees, it is nearly always found that some of the water which the warm air held as vapour is deposited. When air has a temperature of 15°C . (59°F .), nearly five and a half grains of water vapour may be present, whilst at 26.5°C . (80°F .) it may contain as much as eleven grains. If air saturated at the higher temperature were to be suddenly cooled down to the lower one, five and a half grains of water would be deposited from each cubic foot so cooled.

If a glass of ice-cold water be taken into a hot room in which there are a number of people, moisture at once begins to collect on the outside of the glass, because the air in contact with it is cooled, and being no longer able to hold so much vapour in suspension, deposits it on the cold surface. This may be shown in a neater way by taking two

tin cones of the kind used to mull wine or beer in, filling one with snow or powdered ice, whilst the second is filled with a mixture of ice and salt; on bringing these into a hot room it is seen that the moisture collects in small drops on the surface of the one containing the snow, whilst the second vessel, being below 0° C., the moisture freezes as it deposits, and forms a coating of frost.

In this simple experiment we have the key to the formation of dew and rime or hoar-frost in Nature. When the sun shines down upon the earth, its rays pass through the air and do little to raise its temperature; but striking the earth or other solid bodies, the rays are absorbed, and the earth rapidly becomes warm, and it in turn heats the air in contact with it. Now the earth always contains large quantities of moisture, and under the influence of the warmth of the sun this rapidly evaporates, and remains as invisible vapour suspended in the warm air; but presently the sun sinks lower and lower on the horizon, and finally sets, leaving nothing but the warm glow in the western sky to mark its going.

This is the time that Nature commences to manufacture dew. The moment the sun sets the earth begins to cool down again; and in the same way as the earth gets warmer quicker than the air, so it also cools down more rapidly, and radiates its heat into space without appreciably altering the temperature of the air. A time soon comes, however, when the earth has become much colder than the air, and then it begins to cool the layer of air in immediate contact with it, and causes the air to render back to earth once more the moisture which it had taken up during the sunny day.

But now trace the wonderful way in which Dame Nature

does her work. In the day the water vapour was collected from the soil, the brook, and the pond—where is it that Nature re-deposits it? Do you find dew on the barren rocks, on the road, or on the house? Certainly not; it is the blade of grass, the waving leaves, and the thousand and one other forms of growing vegetation which tap the moisture from the air and collect the dew, which, in default of rain, is a necessity for their existence. It is these searchers after moisture that cool most rapidly, and therefore glean the richest harvest; whilst by the time the solid earth has cooled sufficiently to take back any surplus that the air may have to give, the plants have got all that they require.

Nor does Nature waste her favours in too prodigal a style. When the sky is overcast with cloud, and there is every likelihood of rain before morning, you rarely find that any dew is formed. As the earth begins to radiate off its heat, the heat rays are caught by the low-lying clouds and are cast back to earth, and the cooling of the earth's surface being in this way prevented, no deposition takes place. Now the formation of dew is very nearly akin to the formation of fog, and there are very few subjects which can vie with London fogs in the amount of attention they have attracted, and the amount of nonsense which has been talked and written about them.

They have been sat upon by committees, abolished by inventors, and even now are attracting their full share of attention; and yet, with the fall of the leaf, our old enemy is upon us, and the fuming city magnate, as he reaches his office an hour or more late, is fain to admit that the fog king rules just as firmly now as he did in the days before the light of science was brought to bear upon the subject.

The truth is, we may in time clean the fog, and make it

less deleterious and less unpleasant ; but it will never be abolished, and will remain, as now, part and parcel of our London winter, although, when once cleansed, it will be more amenable to the rays of the winter sun, and will not hang for so long over our streets, cutting off the daylight and impeding the traffic.

Fog, whether it be in the form of the white mist which is found in the country or the yellow abomination we know so well in town, is formed by the condensation of water vapour from the air, and this is brought about by any cause which rapidly cools a large volume of moist air.

If, instead of the surface of the ground and the objects on it only being cooled, the air for a considerable height above it is also lowered in temperature, then the moisture which is deposited from it, instead of forming dew, condenses in the air, forming particles so minute that they remain suspended and floating in the air, and constitute fog or mist.

In pure air the mist so formed consists of little else than these minute drops of water, and has no irritating effect upon the eyes or lungs. But in a large town like London the air is charged with an enormous number of minute particles, the heaviest of which settle on any horizontal or roughened surface in the form of dust, whilst the lighter particles continue floating in the air. These particles of dust consist of a heterogeneous collection of all kinds of matter—ground-up particles from the roadway reduced to an impalpable powder by the incessant traffic, small organic spores which are the germs of decay and disease, and particles of unconsumed fuel which have escaped from our chimneys in the form of smoke, and which in larger masses form “blacks.” All these floating solids cool with great rapidity on account of the smallness of their bulk, and in doing so cause the

rapidly cooling air to deposit moisture upon them, and so aid the formation of the fog.

The air of towns in which much coal is used also contains volatile tarry matter, distilled off during the imperfect combustion which takes place in the ordinary forms of fire-grate in use ; and this, condensing with the moisture, coats it on the outside with a thin film, which does much to prolong the existence of the fog ; as when the temperature of the air again rises, the clean mist is once more absorbed by the atmosphere, but the tar-coated yellow fog has its power of evaporation retarded to an enormous extent. Experiments made by Professor E. Frankland show that the evaporation of water in dry air is reduced nearly 80 per cent. by blowing some smoke from burning coal on to its surface.

A London fog seldom extends to any great height, as these carbon-laden particles of moisture gradually sink towards the ground, and the fog is therefore denser nearer the earth's surface than at even a moderate altitude ; so that in nearly every case a visit to the ball of St. Paul's on a foggy morning would be rewarded by a view of the sky.

The yellow characteristics of a London fog are undoubtedly due to the carbonaceous particles and the condensed hydrocarbons which it contains, and which are formed by the faulty methods of combustion adopted by rich and poor alike ; but it must not for one moment be imagined that if complete combustion could be ensured, the London fog would become anything like the harmless country mist, and it is in this that most of the would-be fog reformers have fallen into error.

The impurities due to imperfect combustion certainly are responsible to a certain extent for the power which the fog has of cutting off light, and also partly for the effect which

it has upon the lungs and health ; but it must be remembered that, however completely coal is burnt, all coal contains certain sulphur compounds, the products of combustion of which are found in the air of all large towns ; also that the product of the combustion of the carbon of the coal is carbon dioxide, which is likewise formed during respiration, and which we breathe out into the air, and that these gaseous impurities, instead of being able to freely escape and mingle with the whole atmosphere and undergo natural processes of purification which remove them, as would be the case in clear weather, are confined and kept down by the fog, and rapidly rise above the limits at which they become actively injurious to health. In ordinary air there are about four volumes of carbon dioxide to 10,000 of air ; and when this quantity rises to eight or nine volumes, then it begins to affect the health, whilst the products of the combustion from the sulphur in the coal, in even the smallest traces, affect and irritate the air passages and lungs.

Recent researches have shown that these gaseous impurities rapidly increase in quantity with foggy weather, and during the memorable fog in the early part of December 1882, when so many of the fat cattle at the Agricultural Hall fell victims to asphyxia, the carbon dioxide in the air rose from four volumes to fourteen in 10,000 volumes of air, and it is this increase, quite as much as the products of imperfect combustion, which renders fogs so trying to the system, more especially as other impurities increase in the same ratio.

In the country air these impurities, depending as they do upon dense population, are wanting, and therefore the mist is but little injurious ; but given a densely-populated town, it is impossible to avoid them, as, if the sulphur compounds

were to a great extent done away with by the universal adoption of gas as a heating agent, the carbon dioxide would still remain.

Clean fog or mist would be formed in the basin in which London is built, even if the town were absent, as the clay of which it is chiefly formed, and the river which runs through it, are favourable to its formation; whilst the cloud of smoke generated in London by the annual consumption of 5,000,000 tons of coal not only gives the nuclei on which the water condenses, and the tar oil and tar which coat the particles of water and prevent re-evaporation, but it also, by warding off the sun's rays, prevents the carrying away of the moisture formed by evaporation and combustion, and so keeps the air laden with vapour, and ready to form fog on the first occasion on which it is rapidly cooled.

We must not, however, rush into the error which many observers have done, and put everything down to smoke—a cubic foot of the blackest smoke you can find only contains something less than a grain of carbon, and although the carbon has great colouring power and opacity for light, it is not only the carbon which makes it so dark and dreary during a fog. You have probably noticed how red the sun becomes when you see it even through a white country mist, and perhaps you have also seen how poor a light an arc electric lamp gives during foggy weather, indeed it hardly gives as much illumination as an ordinary gas jet, and these two phenomena are due to the same cause.

The light from the sun is what we term white light, and it is built up of a large number of different-coloured rays, all blended together to form white light, and if we refract a beam of white light sufficiently, we can split it up and see the colours of which it is composed. When a ray of light

passes from one transparent body to another, it becomes bent or refracted, and if we make this bend sufficiently great, inasmuch as some rays are more easily bent than others, we can divide them and make them fall separately on a screen, giving a band of various colours, ranging from violet through blue, green, yellow, and orange to red, and this coloured band is called the spectrum. When these coloured rays come to be examined, it is found that they consist of rays travelling in minute waves, and those at the violet end of the spectrum have very short undulations, whilst the distance from crest to crest of the waves gets longer and longer as you approach the red end of the spectrum. Now when a beam of white light falls upon mist, built up from myriads of little globules of water, the long waves of red, orange, and yellow light are able to find their way through the cloud, but the short rays of violet, blue, and green are hampered and checked by the mist, and so we see the light which reaches us yellow or red in character, the other rays which were necessary to mingle with these to form the white light having been kept back. This may be beautifully shown by focussing a beam of electric light upon a white screen and placing in the path of the ray a glass cell with flat sides filled with a dilute solution of sodic hyposulphite. All the time the liquid is clear a white disc is seen on the screen, but if a little hydrochloric acid is now added to the solution, finely-divided sulphur begins to deposit in it, and as the liquid becomes turbid, so the disc becomes more and more coloured with yellow and orange, and finally becomes of the same orange red hue which the sun assumes when seen through a November fog.

Clouds are practically the same thing as fog, but instead

of being formed close to the earth's surface, they are created from moisture-laden air at a considerable altitude, and the cooling influences which bring about their formation differ from those which are responsible for the fog.

We have before seen that the amount of water which evaporates at temperatures below the boiling-point varies with the warmth of the atmosphere, so that in hot climates it is far more rapid than in cooler zones, and becomes less and less the nearer you approach the regions of cold and ice which surround the poles. Water vapour is also, it must be remembered, lighter than air—indeed it is very nearly the same weight bulk for bulk as coal-gas—and you know how rapidly and readily a balloon filled with coal-gas will ascend in air—so that if you have warm air which is itself expanded with heat, and therefore lighter than cooler portions of the atmosphere, and if moreover this air contains a large quantity of water vapour, you have an ascending current formed. Undoubtedly the hottest portions of the world's surface are to be found within the tropics, where the sun overhead pours its rays directly on to the earth, and here of course evaporation is very rapid—in some places, where the towns are fed from big tanks, it has been found that evaporation has used up more than twice as much water in the day as the supply to the population. Now if you take the globe and examine the portion between the tropics, you are struck by the fact that a very large proportion of the exposed surface is water, and it is here that Nature has established a vast distillery, and as the water evaporates from the surface of the ocean under the influence of the sun's rays, so the moist warm air ascending forms an up-current, and fresh air from the north and south is drawn in to take its place ; whilst in order to replace these

supplies, the ascending air divides and forms an upper current which flows back from the equator overhead in the opposite direction to that which the lower current is taking. If the earth were stationary these currents would flow due north and south, but the earth revolves on its axis once in the twenty-four hours, and as the circumference of the globe is 24,900 miles at the equator, it is evident that anything stationary there is moving with the earth at more than 1000 miles an hour, and although the air nearest the earth moves with the earth, still there is a certain amount of friction which deflects these currents from due north and south, and gives them a north or south-easterly direction.

As the warm moist air ascends from the surface of the sea it rapidly expands, because the greater the altitude the less will be the pressure of the superincumbent air above it, and as the pressure falls, so does the volume of the moist air expand. We have seen that expansion in gases always means absorption of heat, so that the ascending current of air cools by its own increase in bulk, and at first does so at the rate of about 1° for every 183 feet rise. Had the air contained the largest possible amount of water vapour which could have evaporated at the particular temperature at which it commenced to rise, a very small increase in altitude would have been sufficient to cause some of it to condense ; but air is never quite saturated, so that it is some time before this fall in temperature begins to affect the water vapour, and by the time vapour begins to condense as cloud, it is probably being rapidly borne away north and south by the great overhead currents.

As soon as the water vapour commences to condense, the latent heat of the vapour is liberated, and checks any further condensation until this new supply of heat is used up.

When the water vapour condenses, it does so in minute particles, which, although specifically heavier than air, are so small that they are not able to overcome the atmospheric friction, and so float as the overhead fog which we call cloud. By the time this has taken place, the current has probably borne the cloud over some of the big continents, and the small particles of water coalescing together, gradually grow bigger, and having reached a size at which they can overcome the friction of the air, descend to the earth as rain. Should the cloud reach a current of air below the freezing-point, the water particles freeze together in most beautiful crystalline forms, and form the snowflake, whilst if the rain-drop after formation falls through a region below 0° C., hail is the result.

When the rain reaches the earth, some of it runs off the surface to the nearest stream, and we call it surface-water; whilst the remainder sinks through the earth until it reaches a stratum through which it cannot permeate, and collects there until at length it is able to force its way along the stratum and appear once more on the surface as a spring. The surface-water and the spring-water form rills which feed the streams and increase their bulk as they flow down to the river, and the river sweeps down to the sea, bearing with it the dissolved and suspended substances which the water has collected from the earth; and now, having reached the sea and the ocean, it is once more in Nature's great evaporating basin, and the pure water, again distilled by the sun's rays, will leave behind all impurities, and will recommence that marvellous journey, which not only washes and cleanses the earth, but also distributes throughout the globe the heat rendered latent at the equator.

CHAPTER XI.

THE IMPURITIES OF WATER.

As the rain-drop leaves the breaking cloud it is the purest form of natural water, but from that moment it commences to dissolve and take up foreign substances, mostly practically innocuous to health, but in some cases of a highly deleterious character.

The statement that rain-water is the purest form of natural water needs some qualification, as will be seen if one reflects for a moment on the black sludge which is to be found in most town water-butts, and which gives the water an odour far more suggestive of putrefaction than of purity. When rain-water is collected from a clean country roof, or from the sides of the hills, no purer or better water can be found, and the foreign matters to be found in it consist only of such gases as it has collected from the pure air through which it has fallen; but in the neighbourhood of a big town, as already pointed out, the rain has had an important part to play in cleansing the air, and has washed from it the suspended solids, the germs, the ground-up mineral matter, and the blacks formed by the incomplete combustion of solid fuel in our grates. Charged with these, it then falls upon the

roofs, which have formed the settling-place of yet more of the heavier particles of solid matter, and when it has washed these more or less completely away, we store it in the water-butt, and leave it to Nature to purify by her methods of putrefactive decay, which in time would free it from organic contamination, whilst the mineral matter settles as a layer of mud at the bottom of the butt.

Rain-water collected away from towns and their impure atmosphere contains, dissolved in it, oxygen, nitrogen, carbon dioxide, and traces of ammonia salts, nitrates and nitrites. Oxygen and nitrogen are not found dissolved in the water in the same proportion as they occur in our atmosphere, as the oxygen, being more soluble than nitrogen, dissolves in a higher ratio.

Of the dissolved gases in water, oxygen has undoubtedly the most important part to play, as it is this dissolved oxygen which, when the water is circulating on the earth's surface, not only supports fish life, but also purifies the running streams from sewage contamination, which would otherwise render the water unfit for human consumption. In doing this great work the oxygen is itself used up, and where much organic contamination exists but little oxygen is to be found. A sample of water taken from the Thames anywhere above Kingston will be found to contain about 52 cubic centimetres of gas per litre of water, and of this quantity 7·4 cubic centimetres will be oxygen; if, however, a sample be taken at Hammersmith, the organic impurities present will have used nearly one-half this quantity, and only 4 cubic centimetres will be found to the litre, whilst at Somerset House the volume will have been reduced to 1·5 cubic centimetres; whilst between London Bridge and Erith barely a quarter of a centimetre will

be found, as it is over this stretch of water that the greatest contamination exists; below Erith the proportion of oxygen begins to rise again, and by the time the Nore is reached, the proportion of oxygen present once more has reached the normal quantity. The nitrogenized organic matter due to sewage contamination is built up principally of the elements carbon, nitrogen, and hydrogen; and the dissolved oxygen attacks these in the same way as in slow combustion or decay, and burns up the carbon to carbon dioxide, the nitrogen to nitrates and nitrites, whilst the hydrogen becomes, during the combination with oxygen, converted into water, and so Nature rids her great cleansing fluid of its most dangerous and deleterious impurity, and by converting it into substances harmless to life, once more leaves the water fit for the support of human life.

That portion of the rain-water which sinks into the ground has first to penetrate the top and subsoil, which always contains large quantities of decaying vegetation, and is therefore full of the chief product of decay, *i. e.* carbon dioxide. Being brought in close contact with this gas, the water, as it slowly filters through the soil, becomes saturated with it, and bearing it in solution, it penetrates the earth below. Here it meets with many substances, such as common salt (sodic chloride), compounds of magnesium and sulphate of lime, small quantities of which the water dissolves by its own solvent powers; but it also meets with other bodies, which, although practically insoluble in pure water, can be dissolved by the aqueous solution of carbon dioxide, and chief amongst these is chalk or calcic carbonate, whilst to a lesser degree the same action occurs with the carbonates of magnesium and iron. These substances are converted by the solution of carbon dioxide into soluble

bicarbonates, salts which readily dissolve in water, and charged with these dissolved solids, the water accumulates on the surface of the first stratum through which it cannot penetrate, and in time works its way along to the nearest well or spring. Spring water therefore contains various salts as well as gases in solution, and the most important and abundant of these salts is, as a rule, bicarbonate of lime, which endows the water with the property known as "temporary hardness."

The characteristics of hard water are too well known to need description. We all know the misery of having a water supply which, when we wash in it, curds the soap instead of forming a lather with it, which roughens and irritates tender skins, and which is even suspected of rendering us dyspeptic when we use it for drinking purposes over a long course of years.

The hardness due to dissolved bicarbonate of lime is said to be "temporary," because anything which will break up this salt and take away the carbon dioxide which enables it to remain in the soluble form, will throw down the insoluble carbonate of lime and render the water soft once more.

If we boil a hard water, the bicarbonate is slowly broken up, and the solubility of gases being dependent on temperature, the hot water can no longer hold the carbon dioxide in solution, and as soon as it is driven off, the carbonate of lime deposits and forms the "fur" in the kitchen kettle, or the far more serious boiler deposit, which is one of the greatest troubles the user of steam power has to contend with. The cook, by placing a marble in the kettle, prevents the deposit from binding into a hard mass, as every time the kettle is moved the marble, by running about, breaks up

the layer of incrustation, and keeps it stirred up so that it is transferred in small doses to the teapot and saucepan ; but this ready method is not available for use in the steam generating boiler, and the deposit increases and thickens, causing waste of fuel and injury to the boiler plates, until at length a thorough clean-out of the boiler has to take place.

The addition of any substance which will combine with carbon dioxide will in the same way cause the softening of a temporarily hard water, and in many places water of this character is rendered soft by adding slaked lime to it in the required proportions—the lime combines with the free carbon dioxide to form carbonate of lime, and this being insoluble, precipitates in the liquid as a white sediment, whilst the original calcic carbonate, having now nothing to keep it in solution, is also precipitated and leaves the water soft and pure. This is known as Clarke's process for softening water, and is used on a large scale at Canterbury, where the water supply, being almost entirely derived from the chalk measures, is so hard as to be unfit for domestic use. This water is run into large reservoirs, and the right amount of slaked lime having been added, it is allowed to stand, and as the finely-divided chalk (calcic carbonate or carbonate of lime) settles out, it leaves the water clear and soft, and also purified from other forms of impurities which the settling chalk has carried down with it.

When we have, by boiling or other means, removed the temporary hardness from water, we become aware of the fact that there is another kind of hardness which still remains, and this is called permanent hardness, because it cannot be got rid of by those processes which serve to soften water rendered "hard" by bicarbonate of lime.

Permanent hardness in water is due to calcic sulphate (sulphate of lime or gypsum) and to the chloride and sulphate of magnesium, substances which are dissolved by the solvent power of the water itself; and these can only be got rid of by distillation or by the use of some chemical means, which will convert these soluble salts into insoluble bodies.

Not only is hard water unpleasant for domestic use, but it causes an enormous amount of waste, and we become aware of the economic importance of the kind of water we use if we consider merely one of its actions—the waste of soap which it causes.

Soap is a definite chemical compound, and consists of the oleates and stearates of sodium; these dissolve in soft water and form a lather when we wash with them, loosening the dirt on our skin.

If we examine the skin we find that it is full of minute pores, one set discharging waste secretions from the body, whilst a second set furnish oily secretions which keep the skin smooth and soft; and it is these oily exudations which catch and fix the dirt on the skin, and inasmuch as oil is not soluble in water, no mere washing in cold water without soap will loosen the dirt; the soap, however, by acting on the oil, does this, and enables the dirt to be then removed by the water. If, however, the water contains lime or magnesium salts, these at once attack the soap and decompose it, forming insoluble oleates and stearates of lime and magnesium, a process known as “curding”; and until all the lime and magnesium salts present in the water have been in this way used up, no soap will be available for cleansing purposes.

We take advantage of this action to determine the relative

hardness of waters, by seeing how much of a soap solution of known strength a given water can convert into these insoluble compounds.

The supply of water, for instance, at Greenwich is derived from deep wells in the chalk, and on analysis is found to contain—

Temporary hardness.	Calcic carbonate	...	16·30	grains per gallon.
Permanent hardness.	{ Calcic sulphate	...	5·37	"
	{ Magnesian sulphate	...	0·93	"
	{ Magnesian nitrate	...	1·20	"
	Sodic chloride	...	2·64	"
	Sodic nitrate	...	1·21	"
	Silica, alumina, &c.	...	0·97	"
			<u>28·62</u>	

The hardness of a water is expressed in degrees, one degree of hardness representing the soap-destroying power imparted to one gallon of it by the presence in solution of one grain of chalk; so that when we say that a water has ten degrees of hardness, we mean that it contains ten grains of chalk per gallon of water, or its equivalent in other lime and magnesium salts. The Greenwich water supply is said to have twenty-four degrees of hardness, 16·5 of these being due to temporary and 7·5 to permanent hardness.

Now one degree of hardness will use up and waste ten grains of soap per gallon of water used, and with large quantities of a hard water this rapidly mounts up to a very high figure. For instance—

Degree of hardness of water used.	Pounds of soap wasted per 100 gallons of water.
5°	3·66
10°	7·31
15°	11·12
20°	14·75
25°	18·41

—and the enormous amount which this represents, if applied to a largely populated town, may be imagined.

Glasgow used to have a very hard water service; and when this was changed, and the Loch Katrine water was supplied in its place, it made a difference of several thousands in the money annually expended in soap.

The surface-water, which runs off from the face of the earth, contains the gaseous impurities of rain-water and very few dissolved solids, it performs the function of washing the surface of the land over which it passes, and bears away with it in suspension large quantities of insoluble matter—twigs, dead leaves, finely-divided soil, and organic refuse; and charged with this it joins the spring-water and flows down to the river, and in the river-water we find blended together all the impurities of rain, spring, and surface-water.

During the flow of the river down to the sea, several actions take place which tend to alter the proportions of substances present in the water. We find the organic matter brought down by the surface-water being attacked and oxidized into harmless compounds by the dissolved oxygen, and it is also found that the contact of the large surface of water with the air causes the water to give up some of the carbon dioxide it held in solution, and as a result, some of the calcic carbonate is precipitated, and river mud is nearly always found to contain chalk, which has been deposited from the water in this way.

The suspended insoluble matter brought down by a large river in the course of the year is enormous; and when the river reaches the sea, the alteration in rate of flow and density of the water causes a rapid settlement of this suspended matter, and forms the "silt" and mud-banks which

impede navigation at the mouth of big rivers. These banks gradually accumulate and become joined to the shore, and slowly the flowing water builds up the coast line round its mouth from the materials collected in its passage over and through the land.

It has been calculated that the Amazon alone discharges into the sea nearly a thousand million tons of solids in the course of a year, whilst the solid matter brought down annually by the Mississippi is equal to four thousand million cubic feet of clay; and these figures give some idea of the enormous work done by water in changing the face of the globe. It is very interesting to compare the amount and composition of the dissolved solids in spring, river, and sea-water, as it gives an idea of the various actions which are at work.

SALTS IN SOLUTION IN SPRING, RIVER, AND SEA-WATER.

In grains per gallon.

	Spring.			River.			Sea.
Calcic carbonate	...	16'30	...	10'80	...		3'32
Calcic sulphate	...	5'37	...	3'00	...		93'21
Magnesian carbonate	...	0'00	...	1'25	...		trace.
Magnesian chloride	...	0'00	...	0'00	...		220'55
Magnesian sulphate	...	0'93	...	0'00	...		144'62
Sodic chloride	...	2'64	...	1'80	...		1850'74
Silica, alumina, &c.	...	0'23	...	0'27	...		trace.

In the spring-water calcic carbonate is the chief dissolved impurity, and this, as well as the other constituents, is considerably decreased in quantity in the river-water by the admixture of surface-water. The differences in the dissolved solids in river and sea-water are so great that it at first sight seems impossible that the sea-water can be

concentrated fresh-water. In the river, calcic carbonate is by far the most important impurity, whilst in the sea-water it is reduced in quantity to one-third its former proportion, and this is brought about partly by its partial deposition during the flow of the river, and to a still greater extent by its being taken from the water by marine growths and life, all fish-shells, coral, and similar substances being built up from it.

The remaining dissolved solids having no such drains upon them, remain in the water and increase in quantity; but inasmuch as the calcic sulphate is not very soluble, the water in time becomes saturated with it, and any further increase in quantity causes the excess to deposit, whilst the sodic chloride (salt) and the magnesium compounds being extremely soluble, have remained in solution and increased in quantity until, from being mere traces in the fresh-water, they have grown to be the chief salts in the sea-water.

CHAPTER XII.

THE PURIFICATION OF WATER.

IT is manifest that as no such thing as pure water is to be found in nature, its fitness for drinking and household purposes must depend upon the character of the impurities present, and if harmful, how far they can be removed by such processes as can be conveniently applied to them.

With the ordinary impurities present in water and derived from natural sources there is but little danger, and it is only the constant consumption of such waters that make their effects noticeable—for instance, there is every reason to believe that water containing much sulphate of lime in solution will in time produce serious derangement of the digestive organs, and as it is also suspected of aiding in the formation of goitre and calculous affections, it is wise to avoid such water; but the injurious character will only show itself after it has been constantly used for perhaps years, and its occasional use will be followed by no apparent ill effects. It is the chance impurities in water which are the real danger, and of these sewage contamination is by far the worst, and may find its way into the water either by leakage from cesspools into adjoining wells, or in many cases by

the passage of sewage into cracked water-pipes which are laid in sewage-laden soil ; by contamination of water stored in cisterns, the overflow from which leads directly into the drains ; or even by the passage of the rain through heavily-manured land, or through churchyards, becoming in this way heavily charged with decaying animal and vegetable matter. The use of water contaminated by any of these means should be avoided, as it is almost sure to produce diarrhoea, to spread fever, or at least to debilitate those drinking it ; whilst in hot climates such water usually causes dysentery and cholera. As we have seen, water dissolves oxygen from the air during its passage through it as rain, and this is of enormous value in nature, as the oxygen so dissolved burns up to a great extent these organic contaminations, destroying them and converting the carbon into carbon dioxide, which is harmless and of great value in rendering the water palatable, whilst the nitrogen is converted into nitric acid. This natural purifying action proceeds rapidly in masses of water with a large surface exposed to the action of the air, such as rivers and lakes, but is only carried on slowly in water contained in cisterns and wells, and it is therefore of great importance to consider how such contaminated water can be artificially purified and rendered fit for drinking purposes. The chief sources of our water supply are—

1. Rain-water, and no better water than this can be obtained, as long as the tract of country from which it has been collected is well away from any large towns. Some of the northern towns derive their water supply from the English or Scotch lakes, and no softer or more healthful water could be desired ; and if proper precautions were taken to supply the necessary amount of lime in other ways

to growing children, the health of towns with such a water supply would be found to be above the average.

2. River-water. This is never a very hard water, and the greatest objection to it is to be found in the fact that at some period of its flow it is certain to have been contaminated with sewage, and that during floods this is likely to increase in quantity to a dangerous extent.

3. Spring-water, which as a rule is a hard but organically pure water.

4. Well-water. Perhaps the most dangerous class of water is that obtained from the shallow wells so often found in country villages and towns, and which after heavy rains is almost certain to become contaminated with sewage from cesspools and open drains. Shallow well-water has played a prominent part in nearly all the big epidemics of typhoid and cholera in the country.

In marked contrast to this is the deep-well water, which is generally very pure and free from organic contamination, for should the water supplying it become tainted with sewage previous to reaching the well, the water is almost certain to be purified by passing through large masses of porous soil, which holds oxygen in its pores, and so burns up the organic impurities, rendering them innocuous; deep-well water is, however, usually very hard.

The water obtained from any of the above sources is supplied to the consumers either by intermittent or constant service. The constant supply has many great advantages over the intermittent, as there is no need of large vessels for storage, and the pipes, being always full of water, are not so apt to corrode as when they are alternately full of water and air, whilst the chances of sewage contamination from leaky pipes or sewage-laden ground is greatly diminished.

In the intermittent supply the water is only turned on for a short period during the day, and this renders large cisterns for the storage of the water necessary, and unless these are very carefully attended to by being regularly run dry and thoroughly cleaned out, and when in use are tightly covered in to prevent entrance of soot, dust, and the various solid and gaseous impurities always present in the atmosphere, they are liable to become dirt-traps, and a favourable breeding-ground for vegetation and myriads of microscopic animals.

The gaseous impurities in water can be got rid of by prolonged boiling, and as heat tends to kill the micro-organisms to be found in water, this is an advantage.

Dissolved solids, such as magnesium and calcium sulphates and common salt, can be removed by distillation—that is, by converting the water into steam, which passes away and is condensed, the dissolved solids being left behind, whilst suspended solids, and also some other impurities, can be got rid of by filtration.

In the purification of water by filtration on the large scale, two perfectly distinct means are employed to remove impurities. These are the mechanical and chemical.

The mechanical processes employed by the water companies are as follows :—The water to be purified is first passed into large settling tanks, where the heavier particles separate out by gravitation, the water so partially purified passing on to the filtering beds, which are six to eight feet in thickness, composed of layers of gravel and sand, the grains of which vary greatly in size, and the water passes through these beds at a rate of about 60,000 to 100,000 gallons per hour per acre of bed. By this process the suspended matter only is removed, and little, if any, of the organic matter is oxidized.

In filter-beds of this kind the sand employed must be clean and the grains of a medium size, as fine sand would only tend to choke the pores in the filter-bed. It is important that the top layers of sand, which have to bear the chief part of the work, should be frequently changed and replaced by fresh, well-washed sand, and the whole mass of the bed should be replaced by new carefully-washed material at least every two years.

The drawbacks to this method of filtration are—the space occupied by the beds is very great, the smaller microscopic animals are not removed, and also, if any great increase in the rate of flow occur, it is often sufficient to carry through the deposited suspended matter retained in the pores of the bed.

There are several processes in which chemical and mechanical actions are combined; among these is the “Porter-Clark” process. This process consists of mixing lime-water, by means of agitators, with the water requiring purification; the lime combines with the carbon dioxide of the water, yielding carbonate of lime or chalk in a very fine state of division, which, as it settles down, mechanically removes most of the suspended matter; the water is then freed from the precipitated carbonate of lime by forcing it through a filter press, in which frames, covered by canvas or various media, retain the solid particles.

“Maignen’s” process involves the use of a powder called “Anti-Calcaire,” containing chiefly lime, sodic carbonate, and alum; the lime unites with the carbon dioxide of the water, and the sodic carbonate precipitates lime and magnesium salts in the water as carbonates, whilst the alum coagulates the organic matter, which, in settling down, carries the precipitated carbonates down with it. The “Anderson” process relies upon the action of iron upon the

organisms and organic matter present in the water. When the process was first introduced, it was supposed that iron in the spongy condition was necessary, the spongy iron being obtained by reducing the ores of iron at low temperatures ; but it has since been found that scrap-iron, when well agitated in contact with water, answers quite as well. The action is probably due to the formation of the carbonates of iron by the carbon dioxide present in the water, and on air exposure oxidation ensues with coagulation. Many other processes exist, and are in use to a small extent ; in nearly all alkaline hydrates or salts are first added to combine with the carbon dioxide and precipitate the lime and magnesium salts, the precipitated matter being removed by filtration.

The purification of water on the large scale should always be supplemented by the use of domestic filters, for should any breakdown occur in the filtering arrangements of the companies, the impure water would then be supplied for consumption ; and again, supposing the water be supplied of absolute purity, it will in all probability be fouled by storage in dirty cisterns, or contact with sewage gases ; whilst in the country domestic filtration is the sole purification the water receives before consumption.

The subject of filters is a very important one, as the efficacy of a filter not only depends upon the filtering medium employed, but also upon the treatment the filter receives ; filters are most valuable in rendering water fit to drink, but one must remember a filter will not continue to produce good results without careful attention, and the filter is practically a dirt-trap ; and if this be allowed to accumulate, it becomes a fruitful breeding-ground for the various germs, and these may pass through with the filtered water, so rendering it more impure than before.

Up to about forty years ago the media employed in the filters were merely substances which exercised a mechanical influence on the water—such substances as sponge, sand, cloth, and, in some cases, even paper—these merely mechanically retained the suspended impurities, having little or no action upon the dissolved organic or inorganic bodies; now, however, we possess many filtering media exercising both mechanical and chemical actions, the most efficient among these bodies being carbon in its many forms, and the so-called spongy iron. The functions of carbon, as a filtering medium, seem to occupy an intermediate position between chemical and mechanical action; carbon in the form of vegetable charcoal, when freshly prepared by heating any form of dense wood out of contact with air, has a wonderful power of absorbing gases. The volumes of various gases absorbed by a charcoal of this kind is shown in the following table—

ABSORPTION OF GASES BY CHARCOAL.

One volume of charcoal at 0° C., and 760 mm. pressure, absorbs—

Ammonia	...	...	...	171·7 volumes.
Cyanogen	...	...	...	107·5 "
Nitrogen dioxide	...	...	...	86·3 "
Ethylene	...	...	...	74·7 "
Nitrogen monoxide	...	...	...	70·5 "
Phosphuretted hydrogen	...	...	...	69·1 "
Carbon dioxide	...	...	...	67·1 "
Carbon monoxide	...	...	...	21·2 "
Oxygen	...	...	...	17·9 "
Nitrogen	...	...	...	15·2 "
Hydrogen	...	...	...	4·4 "

The gases so absorbed by the charcoal are rendered very chemically active. The following experiment will illustrate this fact :—If a piece of freshly-burnt charcoal be immersed in a cylinder filled with sulphuretted hydrogen until it has absorbed as much of the gas as it will, and if the charcoal be now placed in a cylinder of pure oxygen gas, it is not at all an uncommon thing to see the piece of charcoal become red-hot, owing to the rapid conversion of the sulphuretted hydrogen absorbed in its pores into sulphur dioxide and water-vapour, which process evolves heat, and so renders the charcoal red-hot.

The power of charcoal to absorb gases receives many practical applications, among them being the employment of finely-powdered charcoal to absorb the evil-smelling gases evolved during the putrefaction of various organic matters, such as fish and meat ; the freshly-ignited charcoal is finely powdered and sprinkled over the substance undergoing putrefaction, and the noxious gases are in this way absorbed by the charcoal, and rendered harmless by the condensed oxygen from the air contained in the pores of the charcoal, which burns them up. Respirators are also made of charcoal, and are largely used by operators employed in works the atmosphere of which is charged with deleterious gases ; charcoal is often employed in the wards of hospitals, exposed in a thin layer in shallow dishes, also enclosed in wire-gauze cages, which are placed in windows, through which contaminated air might have access. The power of absorption of charcoal is not confined to gases, for charcoal is able to absorb many liquid and solid substances. The most active form of carbon is that known as animal charcoal, and is prepared in the same way as vegetable charcoal, only animal matters are used instead of vegetable bodies. Bones are

composed of organic and mineral substances; the average composition of the bones of oxen give a good general idea of the composition of bones—

Animal matter	...	...	...	30.58
Calcium phosphate	...	...	...	57.67
Magnesium phosphate	...	...	...	2.07
Calcium fluoride	...	...	...	2.69
Calcium carbonate	...	...	...	6.99

On heating bones out of contact with air, the animal matter is decomposed with the deposition of carbon, which is distributed in a molecular state of division throughout the mass of calcium phosphate, and carbonate, and the reason why the bone or animal charcoal (containing only 10 per cent. carbon) is so much more active in its absorbent properties than vegetable charcoal (containing 93 per cent.) is its fine state of division, fineness of division aiding chemical action. If some port wine, claret, indigo, or infusion of logwood be placed in a cylinder, and into this is put some of the freshly-prepared bone charcoal, and the mixture is then briskly shaken, on filtering it will be found that the liquids have lost their colour, and in the place of the red port wine a colourless liquid—possessing, however, most of the properties of port wine—runs through the filter, the colouring matter being kept back by the carbon. This decolorizing property of animal charcoal is made of practical value to the sugar-refiner, who filters the brown syrup through columns of the charcoal, obtaining in this way a colourless syrup, from which he crystallizes out the white loaf-sugar. If a water charged with organic contamination, both dissolved and suspended, be filtered through animal charcoal, the char-

coal will act mechanically by retaining the solid particles suspended in the water, and chemically by virtue of the condensed atmospheric oxygen it contains in its pores, which will destroy the dissolved organic bodies, burning them up slowly, but as surely as if they had been burnt in the ordinary way, converting the carbon and hydrogen of the organic matter into carbon dioxide and water, which are not only innocuous, but the carbon dioxide is necessary for the aëration of the water.

This action led the animal charcoal filter to be looked upon as perfect until 1878, when it was shown by the Royal Commission on River Pollution that, under certain circumstances, water that had been filtered through the animal charcoal and was allowed to stand, developed minute organisms, which rendered the water foetid and dangerous to drink. The reason of this serious drawback is that the animal charcoal is often prepared at too low a temperature, as if it be prepared at a high temperature the yield of carbon is lower, so causing a loss to the manufacturer, and the low temperature so employed is insufficient to decompose all the animal matter contained in the bone ; the organic matter then undergoes decay, giving rise to the micro-organisms, which are nourished by the calcic phosphate forming the greater part of the mineral structure of the bone. If, however, the animal charcoal be so prepared that all the animal matter is destroyed, and if most of the calcic phosphate were removed, the animal charcoal would still retain its place at the head of the list of filtering media. Spongy iron is used in Bishchof's filters, and is made by reducing the various ores of iron, such as hematite, by carbon at low temperatures, so as to prevent the fusion of the particles of iron formed, and to present as large a surface as possible to act upon the water.

The purifying action of iron upon water has been known from very early times, and as early as 1857 iron was proposed as a water purifier in the form of bundles of iron wire, about 1 lb. of iron being used to 100 gallons of water, these being left in contact for two days. This process gave good results, but this has been much improved upon by employing iron in the spongy condition, which exposes a larger surface, and so renders the purifying and filtering action much more rapid.

Both animal charcoal and spongy iron appear to aid the destruction of the organic germs present in water. The germs are composed of the four elements, carbon, hydrogen, oxygen, and nitrogen, and these are converted by the oxygen dissolved by the water into carbon dioxide, water, and the nitrogen into nitrates and nitrites. The water in passing through the iron dissolves a certain quantity of it, and in order to remove this, the water is made to pass through a layer of fine sand and black oxide of manganese, which precipitates and retains the iron as ferric hydrate.

In Maignen's "Filtre Rapide," the medium is animal charcoal treated with acetic acid to remove calcic carbonate and a portion of the calcic phosphate, and then treated with lime-water to neutralize the acetic acid; the prepared charcoal is then placed round a china cone covered with asbestos cloth, the cone giving a large filtering surface and also great increase in rapidity of filtration. This, however, is attained at the expense of the mass of material which the water has to pass through. Perhaps the best filtering medium at present in use is an artificial compound called "Carbalite," which possesses the best properties of both spongy iron and animal charcoal, and has all the purifying and decolorizing powers of both, but is far superior

to animal charcoal, since it contains no phosphate or nitrogenized animal matter tending to produce and nourish the micro-organisms; and as it also contains iron, by the dual action it removes the organic matter and purifies water far more effectually than any other known substance. In most ordinary filters elegance in form is more often looked to than efficient filtration, and the householder will, in nine cases out of ten, choose a filter which will form a handsome sideboard ornament, rather than an inelegant but effectual purifier; this, however, is not the case with the carbalite filter, for it exposes a large mass of filtering material at the expense of form, and so renders the purification of the water effectual. In the domestic carbalite filter the water to be purified is passed through a thick layer of the medium, which is placed between two perforated plates connected by a screw carrying a bolt, so that by unscrewing the bolt the passage of the water may be made more rapid, and by tightening, the rate of flow may be greatly diminished, so that if a water contains but little suspended matter, the flow may be accelerated; and, on the other hand, if the water be very impure, the passage of the water can be retarded. Another very valuable feature of this filter is the ease with which it can be cleaned, as when the carbalite becomes fouled, it can be removed and renewed by unscrewing the bolt and removing the top perforated plate. The water having passed through the medium, collects in the bottom chamber of the filter, and is drawn off ready for use by a tap in the side.

The relative value of "carbalite" and "animal charcoal" in destroying organic matter was tested by taking two filters of equal capacity, and charging one with carbalite and the second with animal charcoal, equal quantities being used

in each case; the animal charcoal used being the prepared form used in Maignen's filters, and being aided in its action by an admixture of some very finely-divided carbon, which has been found to render the filters more efficient.

Water taken from the Thames at Greenwich was filtered through these in equal quantities, and at a fairly rapid rate of flow for several days, and then analyses of the filtered waters were made, the organic matter determined as free and albuminoid ammonia in parts per million, whilst the total solids and chlorine were determined as grains per gallon.

EFFECT OF FILTRATION.

Thames water before filtration.				After filtration through			
				Carbalite.		Animal charcoal	
Total solids	...	...	110·50	...	80·50	...	76·50
Chlorine	...	...	42·90	...	32·20	...	30·30
Free ammonia	...	...	2·70	...	0·64	...	1·70
Albuminoid ammonia	...	...	1·36	...	0·10	...	1·17

—showing that carbalite had removed 80 per cent. of the impurities present, whilst the animal charcoal had removed 54 per cent.

Doulton's "Manganous carbon" filter consists of a block of prepared carbon covered by a mixture of animal charcoal and black oxide of manganese. The black oxide of manganese is supposed to undergo partial reduction, giving up oxygen to attack and destroy the organic impurities, becoming itself reduced to a lower oxide.

The silicated carbon filter also consists of a block of prepared carbon, covered by the powder of silicated carbon, made by heating shale and other carbonaceous substances with clay out of contact with air.

No form of filter should be employed that depends upon

a block alone for its purifying action, as the block becomes quickly coated with slime from the water, which, if unattended to, soon commences to decompose, giving rise to organic growths which contaminate the water that it is supposed to purify.

As pointed out, all forms of filters require most delicate attention, as it is only by the most careful treatment that the maximum purifying action can be attained, and it must be remembered that the filter is actually a dirt-trap, retaining the refuse matter from the water, which, like the contents of the ordinary dust-hole, is prone to become a nuisance if not regularly attended to and cleaned out. In using a filter the solid impurities are deposited in the pores of the filtering medium, and as soon as the pores become choked with the impurities so retained, all further mechanical and chemical actions cease, and the filter, instead of purifying the water, actually renders it impure.

This point has been very clearly demonstrated during the last few years by the researches of Dr. Percy Frankland in his biological examination of waters, and he has shown, by determining the number of micro-organisms in various waters before and after filtration, that at the end of a month at latest, animal charcoal tends to multiply to an enormous extent the number present, but for twelve days to a fortnight it entirely removes them; if harmless germs be taken into the system of a healthy person no serious evils arise, but a filter that will allow harmless germs to pass, will also allow the germs of cholera and typhoid fever, and in fact any germs of disease, to pass through. On this account, therefore, it is obvious that a filter requires frequent cleansing and changing; in all the ordinary forms of charcoal filters this should be done every three weeks at least, in order to

ensure safety, whilst even with spongy iron and carbalite, a couple of months is the outside period during which they can be with safety continuously used. The most important point in a domestic filter, using any form of carbon, is that every part of it should be easily got at, and the filtering medium removed every few weeks, and either replaced by new material or else the old thoroughly revived by washing it with boiling water and then baking it in a quick oven.

This cleans out the pores of the material and allows it to condense a fresh supply of oxygen from the air, which it can then use for the purification of water for another few weeks. A filter used, as is too often the case, for sometimes years at a time, becomes an active source of danger, as it is only for the first few weeks that it purifies the water, and after that time, the filtering medium becoming fouler than the water, only tends to render it more impure. The blocks used in some forms of filters must not be baked in an oven, as they are generally made by casting the filtering material into the required shape with pitch, and as this is rarely carbonized at a sufficiently high temperature to destroy its properties, baking often causes the block to soften and lose its shape. All that can be done with a block of this character is to once a week scrub its surface with a hard brush and boiling water to remove the dirt, and then dry it in a current of air.

When water is heated it is converted into vapour, and this may again be converted into water by cooling it. In this way the distilled water is made, which is used in the various manufacturing processes, in pharmaceutical preparations, and for drinking purposes where spring and well-waters are not available, as on board ship, or in countries where the water, if attainable, is unfit to drink. The usual

method for preparing distilled water for drinking purposes is as follows :—The water to be distilled is placed in an iron or copper still, which has a dome-shaped neck fitted into the top of it, carrying a copper tube lined with tin ; this tube is connected at its extremity with the condenser, consisting of a tinned tube, which for economy in space is coiled ; this passes water-tight through a tub through which cold water is constantly flowing ; the still is now heated, and as the water boils the steam evolved is passed on into the condenser, where it is again condensed to water. In certain cases, as on board ship or in manufactories, where steam is a waste product, instead of allowing it to escape it is condensed and used for various purposes.

Distilled water has a very sickly taste, owing to most of the air and carbon dioxide found in ordinary water having been driven out by boiling, and in order to render the distilled water palatable, it is again charged with air by brisk agitation in contact with it, or by passing the distilled water through columns of charcoal up which air is allowed to flow ; the water in this way becoming thoroughly aërated. Distilled water and rain-water—which is naturally distilled water—both dissolve lead and copper in small quantities, and these being cumulative poisons, it is dangerous to store either distilled or rain-water in leaden or copper vessels, or use leaden or copper pipes for delivering the water.

In many cases, such as during expeditions, etc., the employment of regular filters is impossible, whilst the water found in such cases is nearly always totally unfit for drinking purposes, being charged to a high degree with all sorts of animal and vegetable life, which are liable to produce dysentery and various other diseases. It is therefore important to consider the rough processes by which

water may be quickly but effectually purified. This is done by sinking an old cask, charred on the inside and pierced with holes in the bottom, in the bed of the stream or pond, and putting into it some fine gravel and the cleanest sand to be found near, in a layer six to eight inches thick, and in the bottom of the cask some wood ashes ; a thin layer of gravel on the top of the sand will keep it from rising with the water, and this will be found to prove a most effective filter for a few days, when it must be cleaned out and recharged.

Where it is impossible to obtain a tub or cask, a few grains of alum (six grains to the gallon) added to the water, or boiling the water with the leaves left after making tea, cause the organic matters to clot together, and on leaving this to stand, settles out, leaving the water considerably purified. The natives of certain countries use a process very much like this ; they add the juices and pulps of certain plants to the water, and this clots and carries down any muddy and suspended matters. Exposure of water to air purifies the water contaminated with organic impurities, and if water be poured from a height in fine streams through air, the oxygen dissolved by the water during its passage oxidizes, and so gets rid of some of the organic impurities and also removes offensive vapour, such as sulphuretted hydrogen. The best way of dividing water into fine streams is to pour the water through a fine sieve again and again from as great a height as possible, the water in this way becoming thoroughly aerated and greatly purified.

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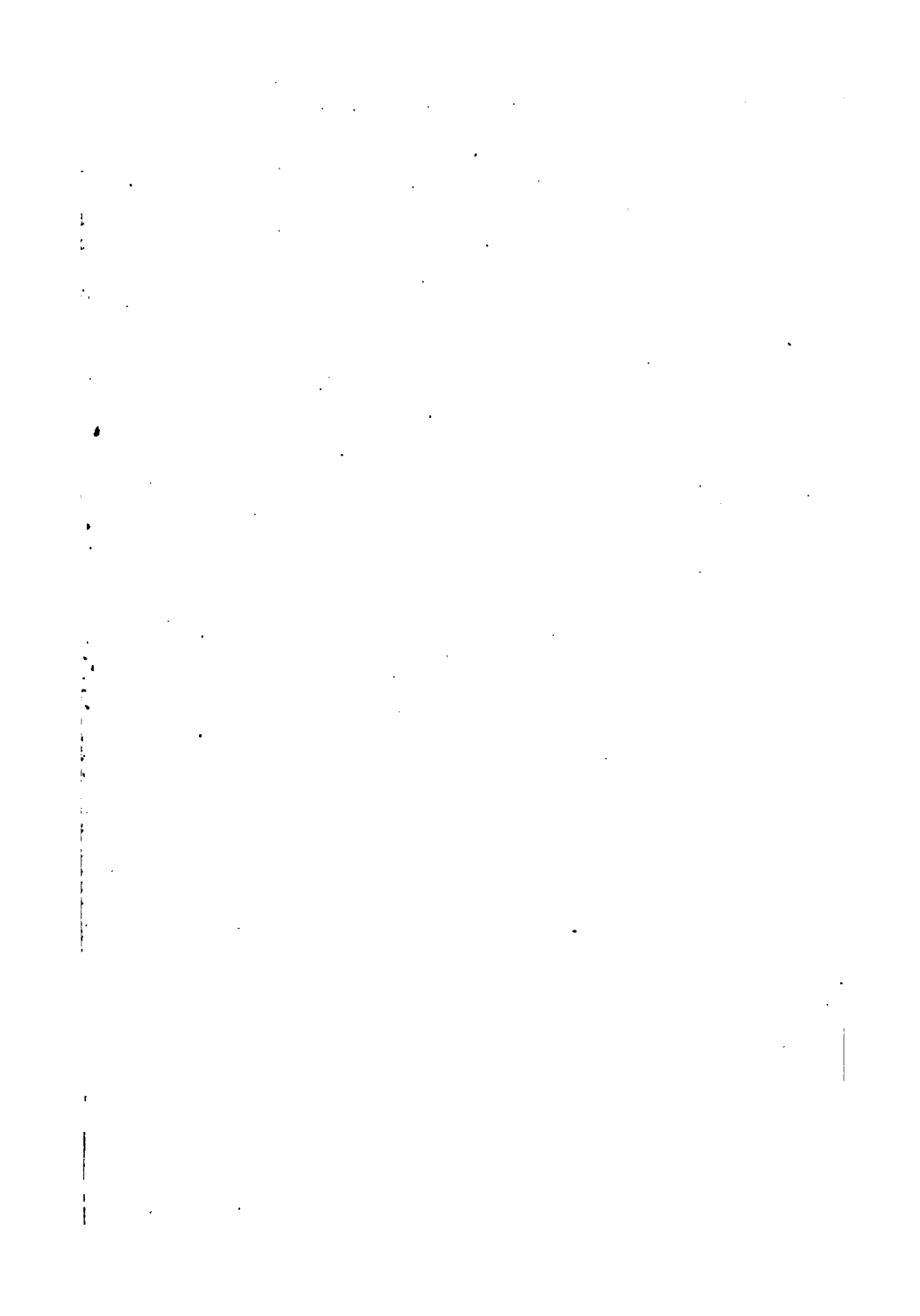
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